# SYSTEM OF ELECTRIFICATION FOR CHICAGO, ST. LOUIS, BRANCH OF THE I. C. R. R. CO.

BY

C. O. HAASE

ARMOUR INSTITUTE OF TECHNOLOGY

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# A PROPOSED SYSTEM OF ELECTRIFICATION FOR THE CHICAGO-ST. LOUIS BRANCH OF THE I. C. R. R. CO.

A THESIS

Presented by

Carl O. Haase

to the

PRESIDENT AND FACULTY

of

ARMOUR INSTITUTE OF TECHNOLOGY

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For the Degree of

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

Having Completeed the Prescribed Course of study in

ELECTRICAL ENGINEERING

MAY 1916.

L. C. Monn
Dean of Cult. St.

Approved
E. P. Freeman
Prof. of Elec. Engineering

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# PREFACE.

The proposed change of motive power for the Illinois Central Railroad has herein been presented in three parts:

The First: the Derivation of the required central station capacity; the second - the system of distribution; the third -the design of the central station.

In the first part, many assumptions had to be made concerning the actual road conditions, as exact information was not obtainable.

In the second part, the overhead construction only was taken in consideration.

The third part is mainly presented by drawings and diagrams as found in the back of this text.

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ACKNOWLEDGEMENT.

The writer wishes to express his appreciation and thanks to the Professors E. H. Freeman, Snow and Moreton and to Mrs. Beveridge for their advice and assistance in the preparation of this subject.

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## INTRODUCTION.

To obtain a clean-cut report, certain limitations had to be placed on such a large problem as that under consideration; the general arrangement of the layout and the working of typical problems rather than the presentation of detailed plans and specifications being the main object.

Also, the discussion of the probable operation advantages to be gained by the electrification, as observed from other roads, fall outside the scope of this problem, as well as any speculations concerning financial returns and outlays after the change; but it can be said that the commercial success of electrification is a question of density of train movements. It has been found that a road must operate 10 trains each way per day, or average a haul of 1,000,000 ton miles per day per 100 mile division, to show a net gain for electric

operation over steam operation. Not only the net haul per mile, but also the power consumption per mile, which is only partly dependent upon the tonnage hauled, wants to be considered, and from present conditions it has been found at that least 100-kw. per mile of single track must be consumed before electrification should be considered.

That these requirements are fulfilled on the road section under consideration, the following pages will show; but these are not the only points that cause the electrification to be a success from the commercial point of view, as demonstrated by the many tunnel electrifications; truly, the prime consideration in these instances was relief from congestion in single track tunnels and elimination of smoke. But the extremely low load factors in these installations are a serious handicap to successful operation and an expensive item to the company in spite of the fact that the road section is taxed to capacity.

To judge from the present train schedule of the road section under consideration, the load factor, both from hour to hour and from season to season, should be rather high so that the combined rated kw. capacity of all apparatus is close to that in use for normal operation.

# PART I.

## Derivation of Station Capacity.

# Part I.

## Construction of Station Geometry.

## A.

### Present Physical Condition of Road Section.

The Chicago-Clinton-St. Louis branch of the Illinois Central R.R. Co. is a standard gauge, double track 300 mile section of the company's railroad system, mostly level, with a short 1.4% grade near Litchfield.

The company operates 2 passenger trains and 35 freight trains per day each way; the latter complete the run in 15 hours, having a schedule speed of 300/15 equals 20 miles per hour; the trains make an average of 21 stops during the run, the stops being nearly equally spaced, the length of each run being an average of 300/21=14.3 miles. The time of run is accordingly 14.3/20 times 60=43 min. The duration of the stop, due to coupling and uncoupling of cars on the siding and making out the train men's papers, is about 10 min. so that the average running time is reduced to 33

min., with an average speed of 14.3/33 times 60 = 26 miles per hour. The distance between trains when equally spaced, is 20x41/60 = 13.7 miles, where 41 = 24.60/35 = time in minutes between trains. At any time, there are 2x300/13.7 = 44 trains on the 300 mile double track section. From these considerations, the graphic time table was laid out for the Clinton section, (fifty miles).

The average train is made up of 70 cars weighing 40 tons each, with a locomotive weighing 200 tons. From this, the total tonnage moved per day of 24 hours is 2x300x35x3000 = 63,000,000 ton miles, or 63,000,000/6 = 10,500,000 ton miles per day per single track, per 100 mile division. If it be considered that to move this tonnage at the required schedule a power of 0.746x26x3000x5,280x10/33,000x60 = 1,540 - Kva per train; or 1,540 x44 = 68,000 Kva total on the road are required. If an overall efficiency of 75% is assumed, it may be estimated that a total of 90,000-kw. are required to do the work of the present steam loco-

motives. Also, when the preformance of other electified roads is considered, it is found that it takes about 40 watt-hours, per ton mile, at the station; then, 63,000,000x40/24 = 105,000-kw. at the station allows another estimate of probable size of the generating station.

B.

Considered Change of Motive Power.

Experience seems to confirm the statement that one large central station, favorably located, with cheap and abundant coal and water supply, is just as probable to give reliable continuous service at the same or even less cost, at the locomotives, as two or more station spread along the line, and less favorably located. Provision in this layout was made for one large central station centrally located at Clinton, Ill., this station to be a steam generating station, burning soft Illinois coal with a coal haul from mine to powerhouse of 21 miles, generating three phase current of suitably high voltage, to be tramsmitted to transformer sub-stations feeding energy to 11,000 volt overhead trolley wires. This system of distribution was chosen because of the success of previous similar installations and on account of the probability of this system being adopted as standard

for American trunk roads.

Calculations were begun for a trolley system providing four substations, each station serving 75 miles of double track, but due to a large voltage drop at the far end, the number was increased to six, each centrally located along 50 miles of double track, feeding single phase current for 25 miles each way, as shown in the scheme of connections.

C.

Probable Power Consumption Under New System.

To make a more accurate estimate of the load curve, the probable power consumption per train had to be derived from the speed-time curve and the motor characteristics. In order to obtain the proper motor specifications, reference was made to train resistance curves given in various hand-books, also calculations were made from various empirical formulas given for train and locomotive resistance. Considerable variations were found from the different methods for the type of train indicated above; finally the values in the following table were accepted as giving a fair average estimate, determined from the formula:

Train Resistance = $4.0+.06V+.33V^2x(1+.1x(n-1))$ lbs.

Locomotive Resistance = 22.2x250+.24V = lbs.

The acceleration resistance for various rates of acceleration was calculated from the formula:

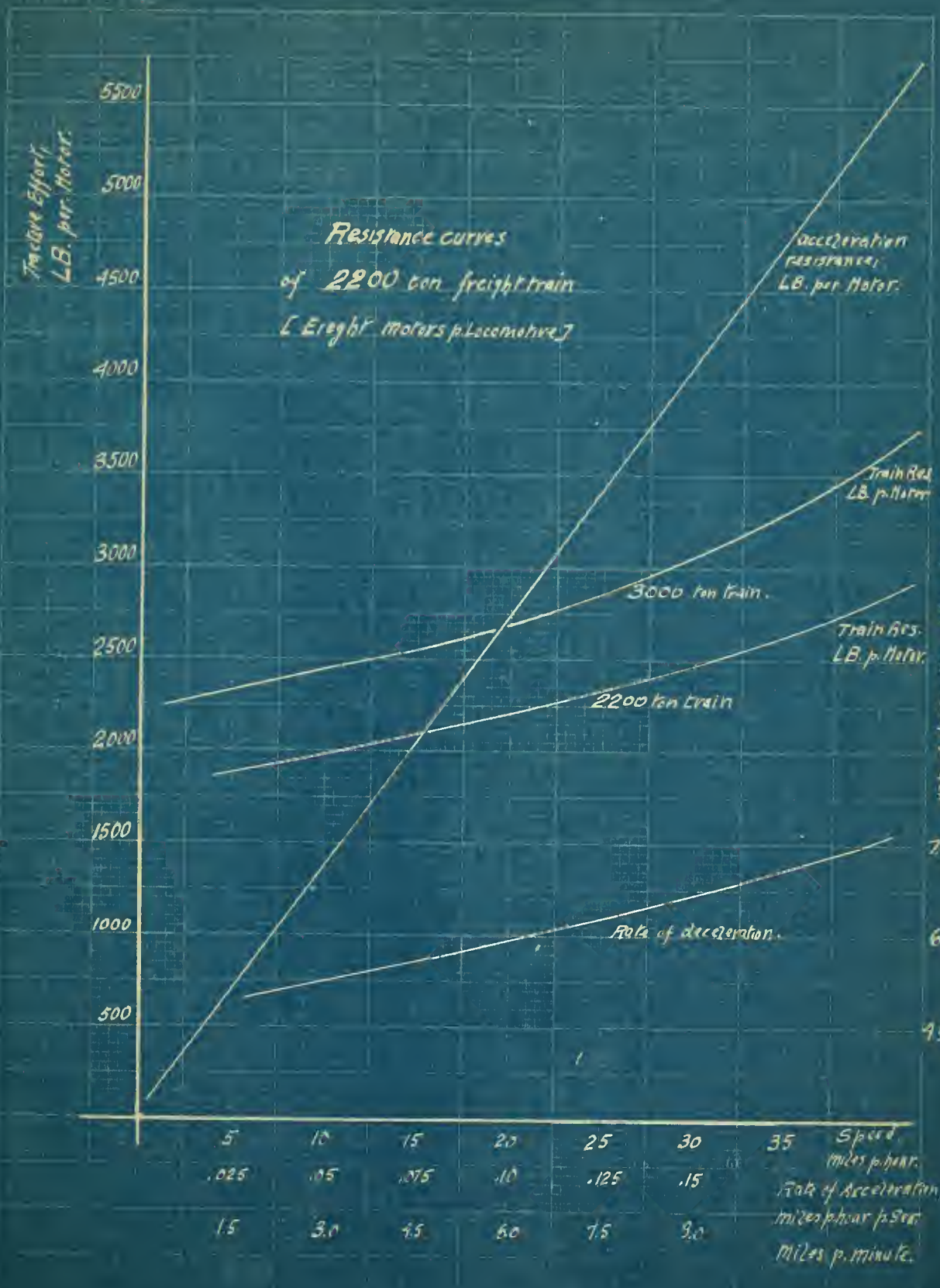
$$T = 100WA \text{ lbs.}$$

The accompanying table and curve sheet show the values for various speeds in lbs. per motor.

| M.P.H. | Total Resist., lbs. Train, Locom. | | Resist. per motor (8 motors) | Lbs. per ton. |
|---|---|---|---|---|
| 10 | 10,400 | 5525 | 2000 | 4.7 |
| 20 | 12,400 | 5600 | 2200 | 5.6 |
| 30 | 14,800 | 5740 | 2500 | 6.7 |
| 40 | 17,500 | 5900 | 2940 | 8.0 |

The drawbar pull at any time will be the sum of the ordinates of the train resistance curve for the speed at that time, and of the acceleration resistance at that time. As the drawbar pull for that class of cars under consideration is limited to 48,000 lbs., or 48,000/8 = 6,000 lbs. per motor, to prevent a breaking of the train, the allowable acceration force had to be limited to a value of 6,000-2,250 = 3,750 lbs. per motor at starting, the train resistance being about 2,250 lbs. per motor at that instant, allowing a rate of acceleration of .82 m.p.h. per min.. For any other time after starting the distribution of the various re-

| | | | | |
|---|---|---|---|---|
| | | | | |
| 10 | 16,400 | 4085 | 1500 | 4.7 |
| 20 | 18,400 | 5320 | 1800 | 3.8 |
| 30 | 14,800 | 6740 | 1800 | 2.7 |
| 40 | 17,500 | 9020 | 1840 | 2.0 |


Resistance curves
of 2200 ton freight train
[Freight Motors p. Locomotive]
Tractive Effort LB. per Motor.
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Acceleration resistance, LB. per Motor.
Train Res. LB. p. Motor
3000 ton train.
Train Res. LB. p. Motor.
2200 ton train
Rate of deceleration.
Rate of deceleration, miles p. hour p. min.
7.5
6
4.5
5
10
15
20
25
30
35
Speed Miles p. hour.
.025
.05
.075
.10
.125
.15
Rate of Acceleration, miles p. hour p. Sec.
1.5
3.0
4.5
6.0
7.5
9.0
Miles p. minute.

sistances and the consequent rates of acceleration were plotted, both for a 3000 ton train and for a 2200 ton train. From these curves the slope of the corresponding speed-time curves was obtained graphically and then transposed to give the acceleration part of the speed-time curves. From these curves and the train resistance curves the specifications for the motors were obtained. An inspection of the curves gives the following performance requirements:

To give a tractive effort of 6000 lbs. for 10 min. at low speed; to give a tractive effort of 2400 lbs. at a speed of 27 m.p.h., at less than rated voltage without exceeding the continuous current rating.

As special information on railroad motors was not obtainable from the manufacturing company's, recourse was had to the railway motor characteristic curves as given in Ritchey's railway hand-book of 1915. Of these motor requirements, only one came up to the specifications, in fact slightly exceeded them. But as one of the limitations of steam locomotives is their small

overload capacity, tending to reduce the elasticity of service as required by the everchanging demands on the road. It would be unwise, by installing electric units of too limited capacity, to offset the principle advantage that electrification offers. While for a railway with frequent stops and short runs, maximum rates of acceleration and resulting long coasting govern the gear ratio and thus the power consumption; for trunk roads the coasting period is practically nil, and the main portion of the power consumption occurs while operating at uniform maximum speed. But, the principle requirements of a locomotive motor is to exert large tractive efforts at low speeds during extended periods without overheating.

A reprint of the curves is found in this text, with a slightly increased gear ratio, so as to give a maximum speed of 30 m.p.h. at full voltage to a 3000-ton train, without exceeding the continuous rating; for lighter trains and lower speeds the efficiency or power factor is not materially lowered as the motors are supposed to be controlled

by compensators allowing various voltages to be impressed on the motor terminals.

From these performance curves and the maximum allowable rates of acceleration as determined from the resistance distribution curves, the speed-time curve was plotted for trains of 3000 and 2200 tons, for 300 and 260 volts across the motor, for a distance of 14.3 miles, to be covered in 33 min.. This allows for a large flexibility of service, making up lost time or keeping up schedule under adverse conditions.

From the current consumption as obtained from the motor characteristic curves and the voltage, the power consumption curve was plotted. Due to high train resistance, coasting for any appreciable time was out of the question, except a few minutes before applying the brakes previous to making a stop.

From this power consumption curve per run and the graphic time table, a load curve for a period of five hours was compiled for a 50 mile section of the road, giving the average load char-

acteristics for one sub-station. To obtain the load curve for the central station, the ordinates of the sub-station curves for equal times must be added; as the ratio (max. load)/(aver. load) = 1.22 only, it is assumed that by judicious train dispatching the overload capacity of the central station takes care of any peaks that may occur in the load curve. From the current curve of the speed-time curve, the average current and the mean effective heating current were determined and tabulated as follows:

| Time (minutes) | Current p. m. | Current .p. m. | Volts | KVA Power p. m. | Total kva. p.loc |
|---|---|---|---|---|---|
| 1 | 1300 | 169x10⁴ | 90 | 117x~~10~~ | 940 |
| 2 | 1300 | 169 " | 170 | 220 | 1750 |
| 3 | 1300 | 169 " | 250 | 325 | 2600 |
| 4 | 1050 | 110 " | 260 | 270 | 2150 |
| 5 | 980 | 96 " | 260 | 255 | 2000 |
| 6 | 950 | 90 " | 260 | 250 | 2000 |
| 7 | 920 | 85 " | 260 | 240 | 2000 |
| 8 | 900 | 81 " | 260 | 236 | 1800 |
| 9 | 875 | 77 " | 260 | 236 | 1800 |
| 10 | 870 | 76 " | 260 | 236 | 1800 |

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Taking the area of the apparent power curve, we find it contains 102,000 kva hours, for 14.3 miles for 300 tons, or 28.6 kva. per ton mile. Multiplying by an efficiency and power factor, as seen from motor characteristic curvess, we get 28.7x86x 90 = 22.2 watt-hours per ton mile on the trolley section. The average apparent power taken by all the motors is 13,900 kva. as observed from the component load curve; assuming an efficiency of 95% of the conversion apparatus in the locomotives, the power taken by the latter is 13,900/.95 = 14,600 kva. The power lost in the trolley, when it is assumed that the total current passes through one-half the length, (assuming uniform current drainage) is; for 14,600,000/4x11,000 = 330 amp., and 25/2 = 12.5 miles double 4/0 B.S. Gauge, of =.258 ohms per mile. Then, $I^2R = 330^2x(.258/2)x12.5$ = 180-kwa. Therefore apparent power delivered per sub-station equals 14,600 + 4x180 = 15,320-kva. For six sub-stations, exclusive transmission line loss, the power at the central station is 6x15,320= 92,000-kva.

# PART II.

## Distributing System.

## A.

### Economic Calculations.

In figuring on the over-head construction, the procedure as outlined in Still's "Overhead Electric Power Transmission", was followed, based on the principles of Kelvins Law for determination of the economic drop. As a duplicate transmission line is used, the voltage drop per mile for the single line was taken as 3/2 of the calculated economic value, giving for normal operation, when both lines are connected in parallel, a drop of only 3/4 of the economic value. This allows the use of but one line without excessive losses. The empirical formula for estimating a proper transmission voltage would indicate a line pressure of about 100,000 volts. But, when the proper size of wire was calculated from the allowable drop and the average current per wire, it was found that this size of wire would not withstand the stresses , due to adverse loading on 300 ft. spans without giving it an excessive sag. When taking a

wire of proper mechanical strength, only a little is added to the cost of copper, while a heavier current carrying capacity is obtained, consequently a lower voltage can be used, which allows a closer spacing of wires and cheaper insulation, also lower structures. To meet all the requirements of economic power transmission, 66,000 volts were used, which allowed the transmission line to be equally strong both mechanically and electrically.

Calculations.

Total Kva transmitted per duplicate line:-

As far as 1 sub-station, (25 miles)--50,000 Kva.

As far as 2 sub-station, (75 miles)--34,000 Kva.

As far as 3 sub-station, (125 miles)-17,000 Kva.

$E = 5.5\ 25 + 50{,}000/(200 \times .746) = 105$-kva.

$E = 5.5\ 75 + 34{,}000/(200 \times .746) = 95$-kva.

$E = 5.5\ 125 + 17{,}000/(200 \times .746) = 85$-kva.

Economic voltage drop $V = 8.1\sqrt{(axp)/(p_1 \times .746)}$

a = % depreciation, (assumed 10%)

p = cost of copper, (assumed $20 per 100lbs.)

$p_1$ = cost of energy, (assumed $16.8 per Kva.year)

$V = 8.1\sqrt{(10 \times 20/13.5)} \times 3/2 = 48.5$ volts per mile.

Adopting a line pressure of 66,000 volts, we have, for current per wire:-

I = 50,000/( 3x66) = 440 amp., in 25 mile section.

I = 34,000/ ( 3x66) = 300 amp. in 50 mile section.

I = 17,000/( 3x66) = 150 amp., in 50 mile section.

To have a drop of 48.5 volts per mile, the resistance per conductor must be:-

R = E/I = 48.5/440 = .110, in 25 mile section.

R = E/I = 48.5/300 = .162, in 50 mile section.

R = E/I = 48.5/150 = .324, in 50 mile section.

From wire tables, we find:-

| Cir. mils. | area. | ohms/mile | RI/mile | total drop |
|---|---|---|---|---|
| 500,000 | .393 | .1095 | 48.46 | 1211 |
| 300,000 | .236 | .1818 | 54.5 | 2740 |
| 4/0 B.S. | .166 | .260 | 39.0 | 1950 |

As it not advisable for railroad work to take a smaller wire than 4/0 B.S. with a resistance of only .260/mile, instead of .324 ohms as really would be sufficient, the middle part of the line has been chosen slightly weaker to offset the surplus carrying capacity at the last

section. With these wires and respective currents the values in the following table have been determined:

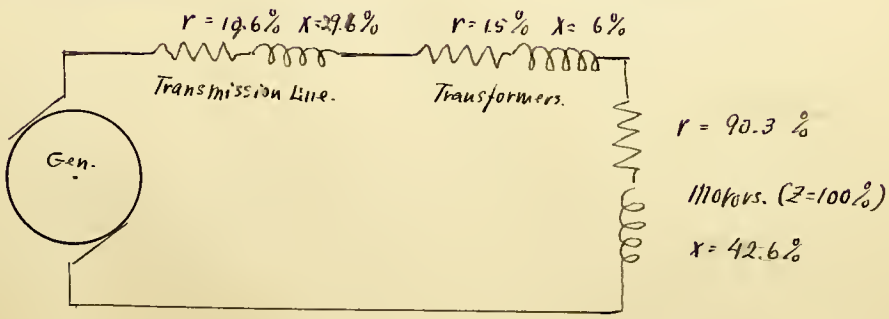
| Cir. mils | Total ohms. | I. | $I^2R$ |
|---|---|---|---|
| 500,000 | 2.52 | 440 | 480 |
| 300,000 | 9.1 | 300 | 810 |
| 4/0 B.S. | 13.0 | 150 | 290 |
| | 24.62 | | 1580 |

Loss in three wires = 3x1580 = 3740-kw.

% loss = 3740x100/46,000 = 8.15%, for one line. When both lines are in use, the resistance to the same current is one-half only, or 4.075%.

The spacing for 66,000 volts between wires, from tables, for 300 ft. spans, was taken as 72", for equilateral arrangement.

To determine the regulation of the line, the probable power factor had to be estimated, as follows:



| | % RI | %XI |
|---|---|---|
| Motors | 90.6 | 42,3 |
| Transformers | i.5 | 6.o |
| Transmission line | I9.6 | 29.2 |
| | 111.7 | 77.5 |

$$\cos.\ \phi = \frac{111.7}{111.7 + 77.5} = .85;$$

Regulation:-

The resistance, total per wire (125 miles) is 24.62 ohms. The reactance, for various sizes of wire is, from tables, for 72" spacing, =(25x.729)+(.291+.3o)5o

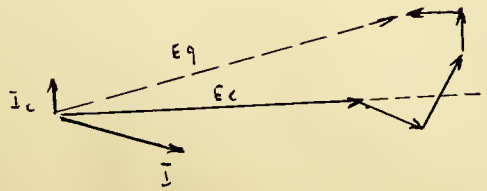
X= 36.425 ohms.

Taking the worst condition, for the sub-station at the end of the line, with the powerfactor =,85. we get for the capacity current, from tables in the St. Handbook for E.E. $I_c$ = 38.3 amp. Average Current=(440x25)+(300x150)50/125;= 244amp.

RI=5970volts RI$_c$=940volts.
XI=8750volts. XI$_c$=1400volts.
Volts to ground=66,ooo/$\sqrt{3}$=38,000.

$$E_g = \sqrt{(E_c + XI\sin\phi + RI\cos\phi + XI_c)^2 + (XI\cos\phi + RI_c - RI\sin\phi)^2}$$

where $E_g$ =generated voltage, for a supposedly



known or accepted value of $E_c$. Taking as an aproximaion $E_c$=52,000 V.; we have 52,000/$\sqrt{3}$ =30,000 V. to ground at the sub-station. Therefore we have $E_g = \sqrt{(5970x.51+8750\cos\phi+940)^2+(30,000+8750x.51+5970x.85-1400)^2}$; or $E_g$=38,500, or volts between wires=38,500/$\sqrt{3}$ = 66,500 V. This calculation shows, that under full load conditions, 52,000 volts can be expected at the substation. This means a regulation of (66,500-52,000)/52,000 = .28 ;

In checking up with Mershon's diagram, we have:

%resistance volts=100x5970/30,000= 19.2%

%reactance volts =100x8750/30,000= 29.1%.

From diagram, pp. 73, Still, %regulation= 31 %.

From this new voltage at the receaving end we calculate the correct current in the last section as:

I= 15,320,000/($\sqrt{3}$x52,000= 170.1 amperes/line/wire.

This makes a difference of (170.1-150)/150= 13.3%. in the current in the last leg of the line.

Total Load:-

For the last two sub-stations at either end of the line, the central station load will be; 2 x 3 x 170.1 x 67,000 = 39,500-kva. For the two middle sub-stations, assuming the loss to be equally distributed along the line, the voltage will be 58,000. Load for the sub-station will be 2 x 15,320 x 67/58 = 35,400-kva. For the two near stations, load equals 2 x 15,300 x 67/64 = 32,000 kva.

Total required capacity, equals 39,500 + 35,400 + 32,000, or a total of 106,900-kva. When moving 63,000,000 ton miles a day, we have 2,380,000,000/63,000,000 = 37.8 watt-hours per ton mile at the station. With 22.2 watt-hours at the motors, we have an over-all efficiency of 22.2 x 100 x 37.8 = 59%.

No-Load Current:-

To get an estimate of the probable load on the generators when no trains are running, the following calculations were made:

Total Debits:-

From Tables in the E.E. St. Handbook, for 4/0 B.S. Gauge copper trolley wire, spaced 150", we find the current per single wire per mile, per 100,000 volts as I = .210 amp. For 600 miles, 11,000 volts this current would be:

I = .210x600x11,000/100,000 = 13.8 amp. for trolley wire, or 13.8 x 11,000 = 154,000-kva. For duplicate transmission wire, spacing 72", average size 300,000 cir. mils; I = .270 per 100,000 volts per mile; for 4 x 125 = 500 miles, 38,000 volts to ground, we have: I = .27 x 500 x 38,000 / 100,000 = 53 amp. per wire, or 53 x 3 x 66,000 = 11,000-kva. For the no load current of the transformers a value equal to 4% of their combined rating, or 2 x 100,000 was taken; equals .04 x 100,000 x 2 = 8000-kva. Adding vectorially we get 154 + 11,000 - 8,000 = 3,154-kva.

Corona loss will not be evident as the voltage between wires is within safe limits of the critical voltage (170,000) for that spacing of wires.

B.

Mechanical Calculations of Transmission Line.

For the different sizes of wire as previously adopted, the following table was obtained from the St. Handbook of E.E., Sec 2, adopting Class B of loading of the wires, as most probable, as observed from the climatic conditions of Western Ill.; namely, as worst conditions occuring simultaneously.

Temperature-20

Wind-43 miles per hour.

Deposit on wires = one-half inch ice crust.

Hard-drawn-stranded copper conductors.

| Cir.mils. | safe tension | Load/ft. Vert. | Horiz. | Resultant |
|---|---|---|---|---|
| 500,000 | 11,750 | 1.525 | 2.345 | 2.640 |
| 300,000 | 7100 | .915 | 1.685 | 2.000 |
| 4/0 B.S. | 5000 | .645 | 1.236 | 1.641 |

From the safe stress per wire as obtained from the previous table, and tables on pp. 932, St. Handbook, E.E., the sag per wire for 300 ft. span was found that will cause a stress not greater than the safe stress.

P = 1875 x 2 x 2.64 = 10,000, for 1% sag.

P = 1875 x 2 x 2.00 = 7,500, for 1% sag.

P = 1417 x 2 x 1.64 = 4,650, for 1.5% sag.

Also the length of the unstressed wire was found from tables for that stress and span to give the proper sag, and was later verified by the graphic method as given in "Still", the curves being contained in this text, also from equation $L = l + (8s^2)/3l$.

Actual length of wire.

Cir. mils.

500,000 ----L = 150.040 x 2 = 300.080 ft.

300,000 ----L = 150.040 x 2 = 300.080 ft.

4/0 B.S.----L = 150.090 x 2 = 300.180 ft.

After these fundamental data were secured, tension-sag calculations were made by the analytical method for various other load and wind

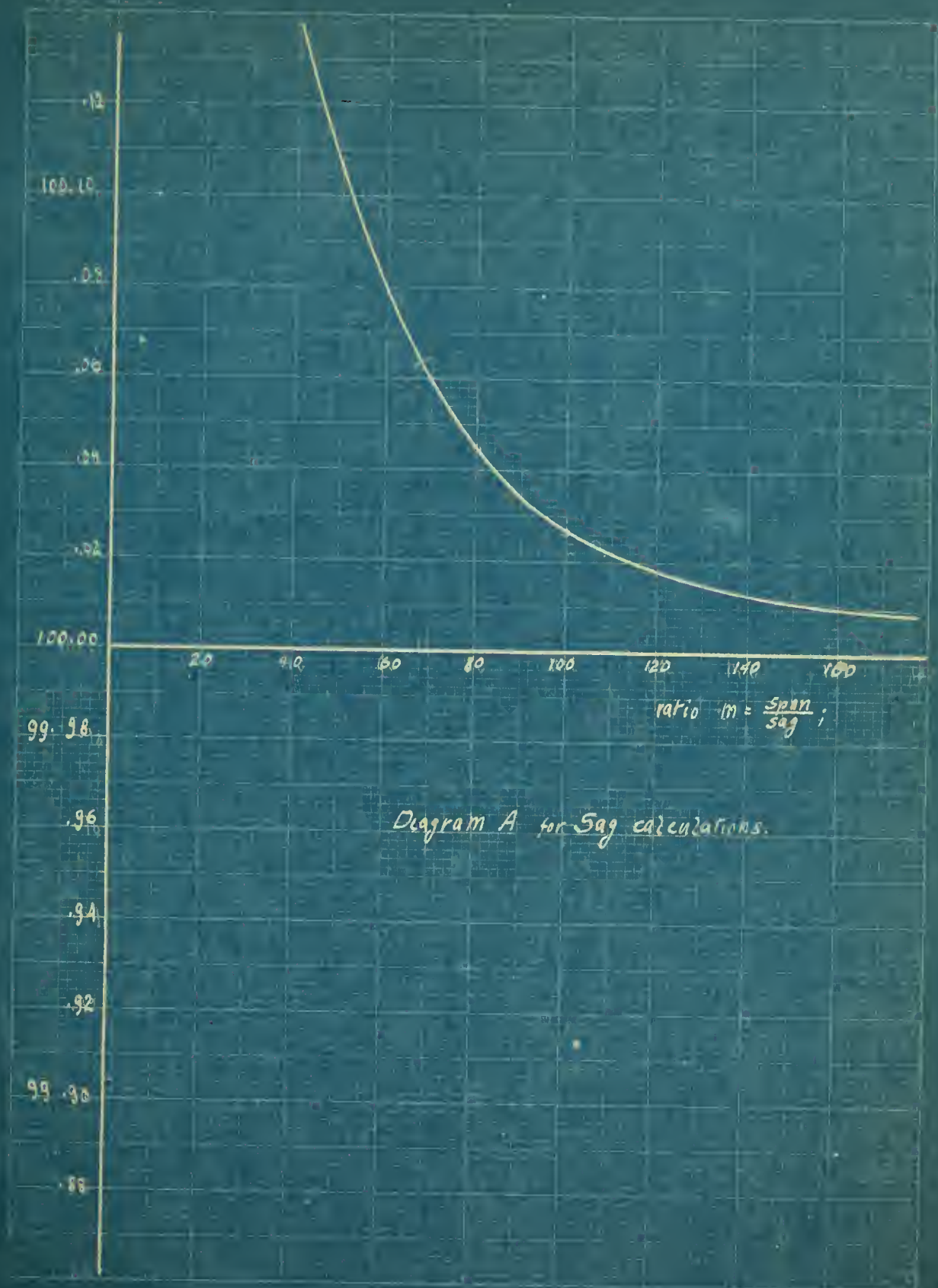



Diagram A for Sag calculations.

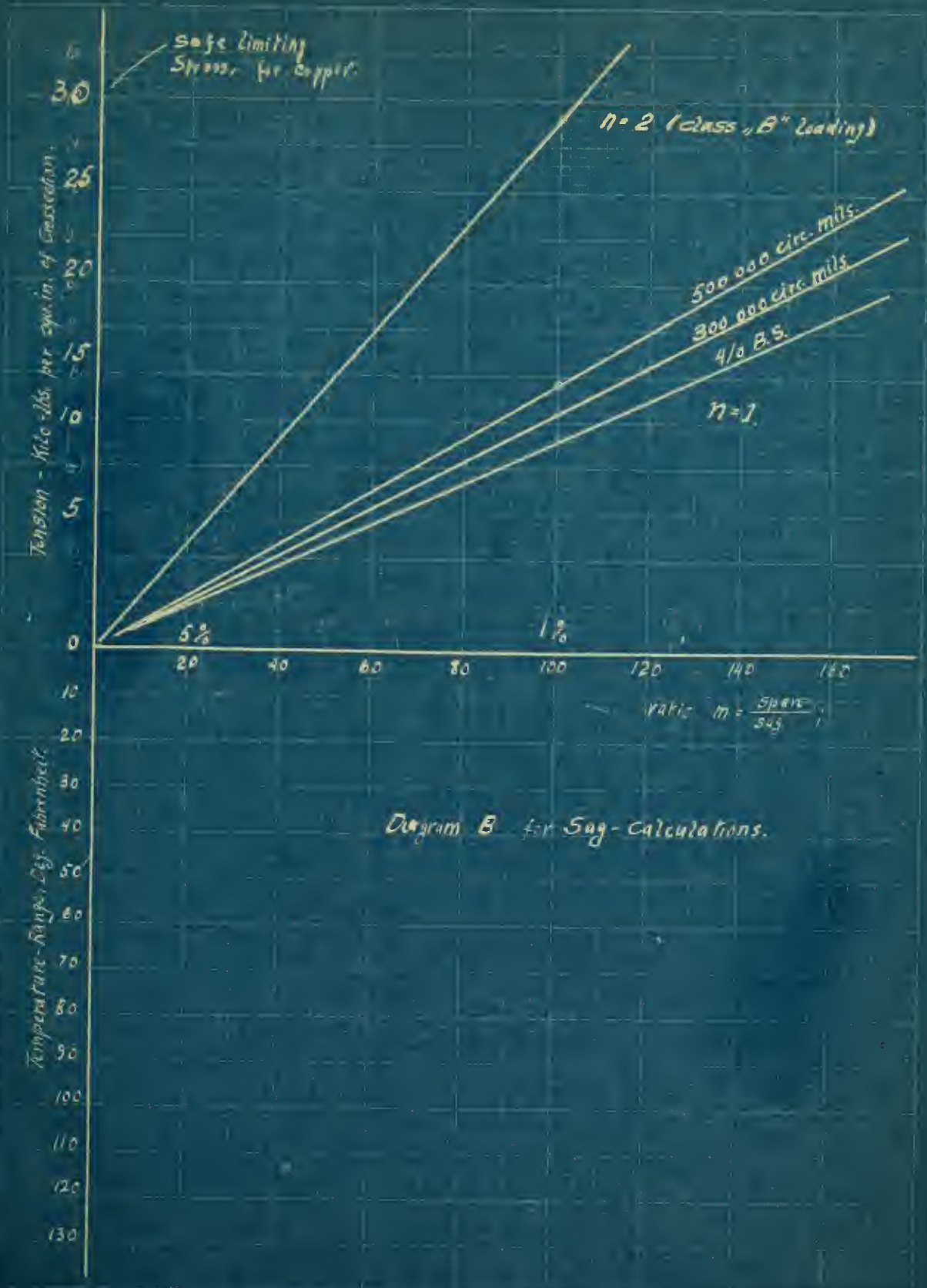
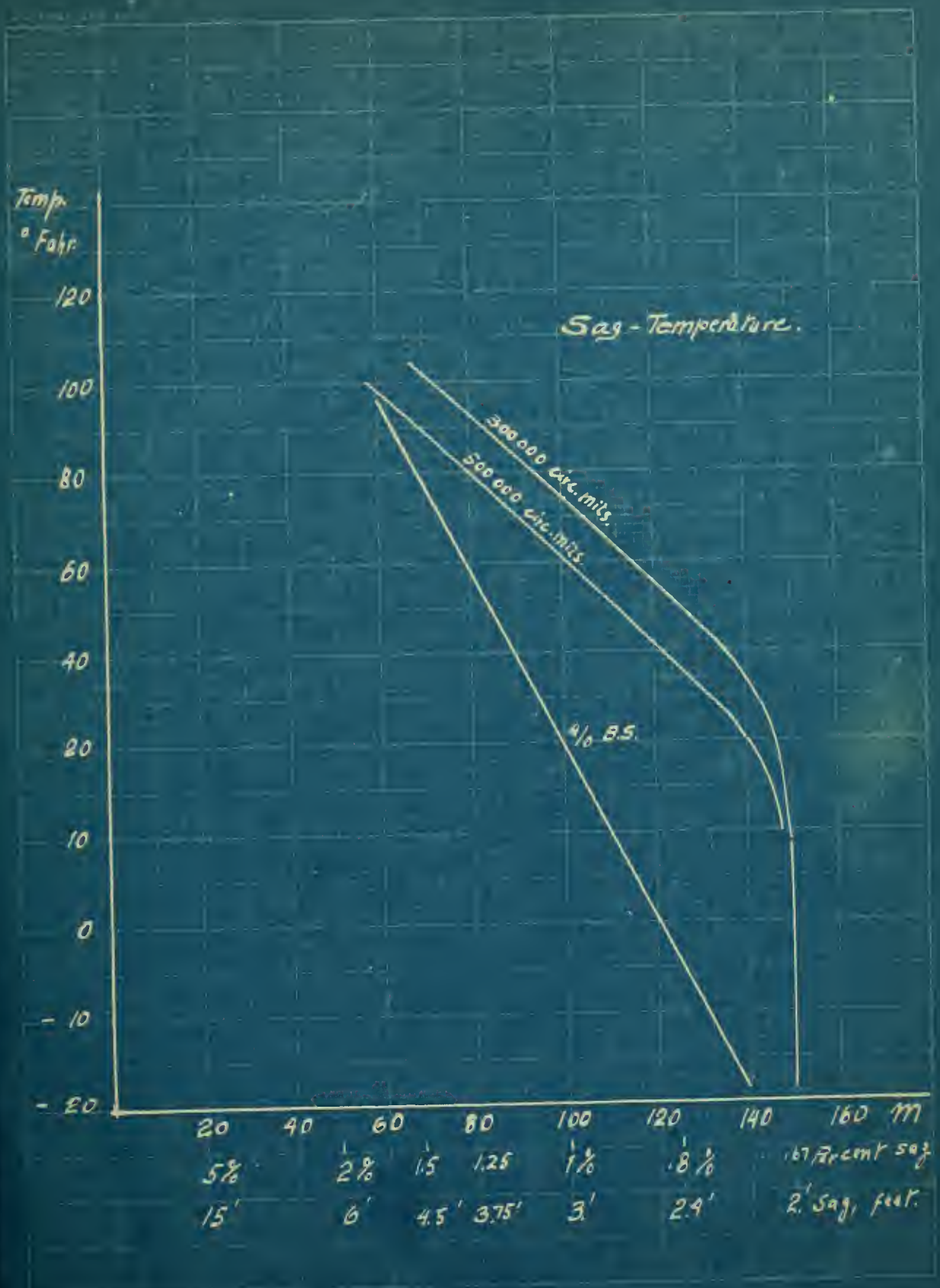
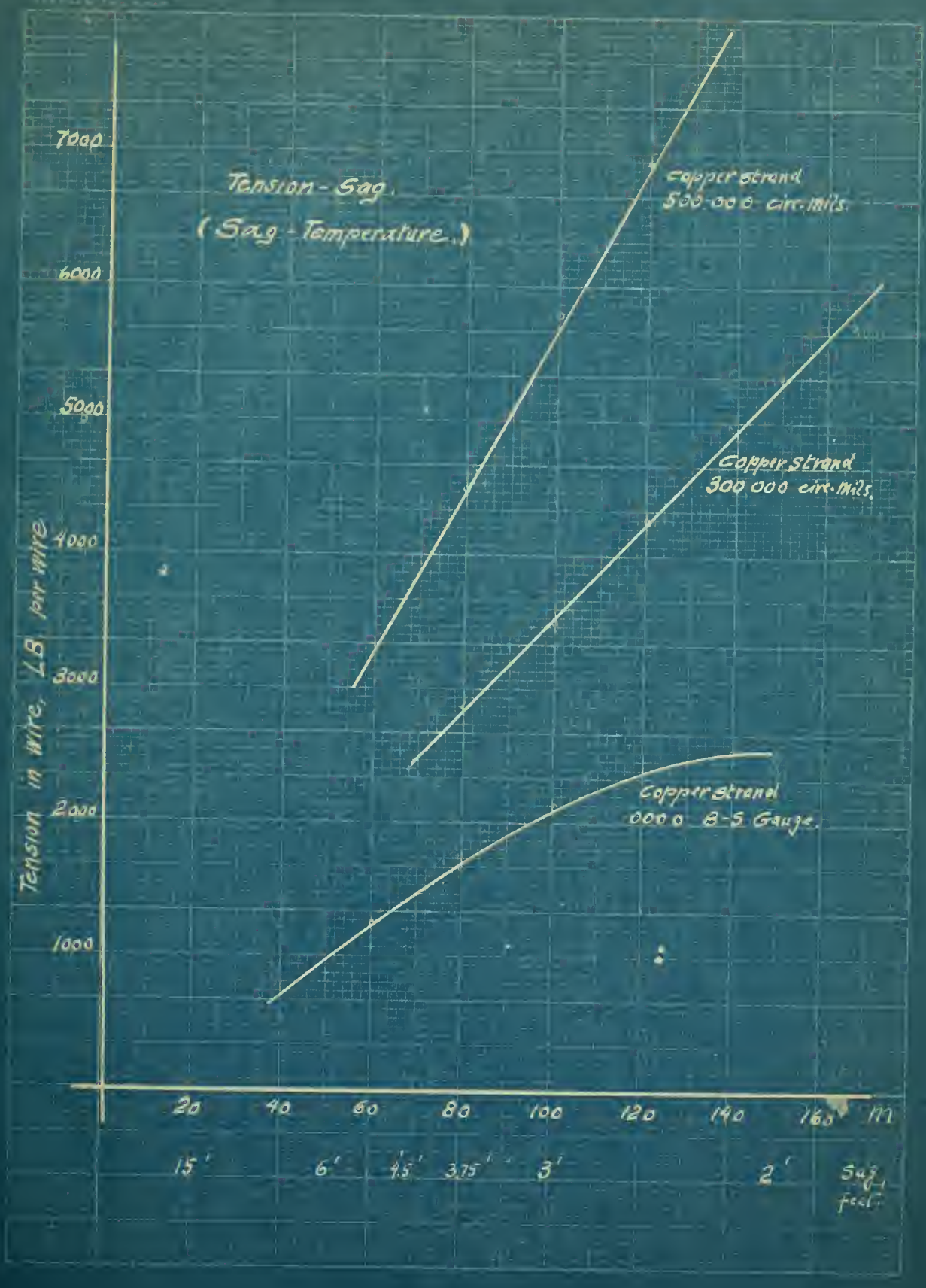
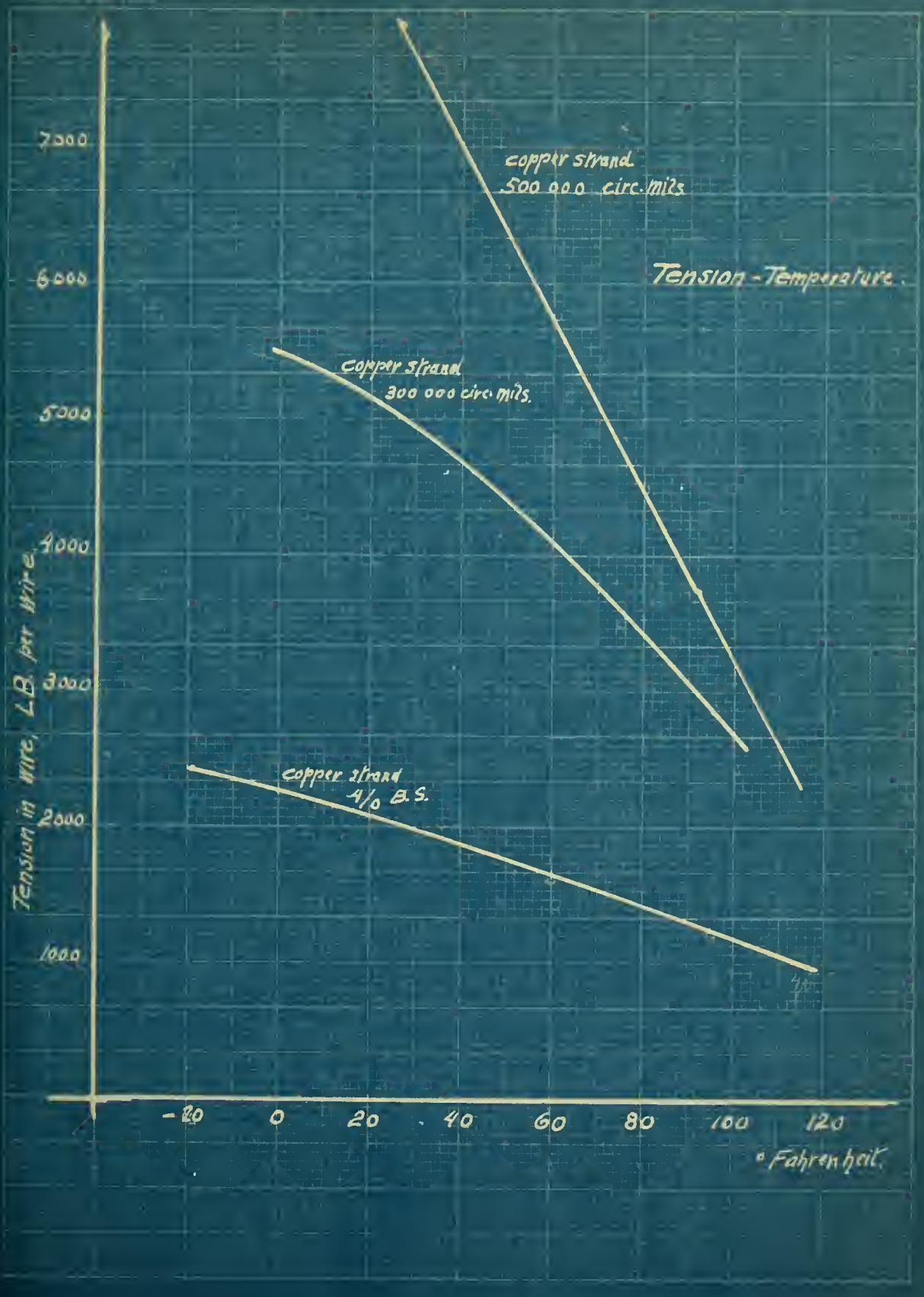



Diagram B for Sag-calculations.


Temp.
° Fahr.
120
100
80
60
40
20
10
0
- 10
- 20
Sag - Temperature.
300 000 Circ. mils.
200 000 Circ. mils.
4/0 B.S.
20
40
60
80
100
120
140
160 M
5%
2½
1.5
1.25
1%
.8⅓
1.67 Percent sag
15'
6'
4.5'
3.75'
3'
2.4'
2' Sag, feet.


Tension - Sag.
(Sag - Temperature.)
Copper Strand
500 000 cir. Mils.
Copper Strand
300 000 cir. Mils.
Copper Strand
0000 B-S Gauge.
Tension in Wire, LB per wire
7000
6000
5000
4000
3000
2000
1000
20
40
60
80
100
120
140
160
177
15'
6'
4.5'
3.75'
3'
2'
Sag in feet.


Tension - Temperature.
copper strand
500 000 circ. mils
copper strand
300 000 circ. mils.
copper strand
4/0 B.S.
Tension in Wire, LB. per Wire.
7000
6000
5000
4000
3000
2000
1000
-20
0
20
40
60
80
100
120
° Fahrenheit.

conditions. The calculations were carried thru on the assumption that the curve was identical to the section of a parabola. This assumption was proved to be approximately correct by actually stringing a fine brass chain, 80" long, between supports, to give a sag of 2%, and measuring the deflection at the sections indicated in the diagram. No deviation was found from the calculated values of the parabola, as shown for the catenary construction. As the sag is small, the difference between the tension at the center of the span and at the point of support was found to be small, and was therefor neglected; all tensions and stresses given are referred to the center of the span, calculated from the formula $P = WL^2 / 8s$, where P equals the tension in lbs./sq.in., at the center of span, and W is the weight per foot of conductor; L is the spaning in feet; s is the sag in feet.

When the wind is blowing transverse to the direction of the line, the loading, and therefor the stress on the wire is increased; this increase

is taken care of by the use of a factor n for various wind velocity's and sizes of wire, as given by curves on pp. 166, "Still". For wind velocity of 43 miles per hour, the following values were obtained for copper conductors, ice coated; for no wind, n evidently is 1.

| cir. mils. | n. |
|---|---|
| 500,000 | 1.6 |
| 300,000 | 1.8 |
| 4/0 B&S. | 2.0 |

This factor is used in the formula for tension-sag relations.

$$T = .485 \times n \times L / s = \text{lbs./sq.in.}$$

Once convinced that the safe limit of stress is not exceeded under the worst assumed condition of loading, the sag and tension for other temperatures, without ice loading, has been determined , which data will be of use when stringing the wires. It was found that the effect of the wind on the bare conductor is exceedingly small and therefore n was taken as unity in the tension-sag formula, when figuring on bare conductors.

Calculations;

Sample, worst condition of loading. cir. mils = 300,000; span = 300ft.; allowable safe tension = 30,000 lbs./sq.in.

T = mnlk; where k = .485 for copper.; m = l/s = 100 for 1% sag., therefor,

T = 100 x n x 300 x .485.

for n = 1, tension is 14,500 lbs./sq.in.; for n = 2, tension is 29,000 lbs./sq.in.

When the extra load due to ice and wind is removed the stress on the wire is reduced and the sag will diminish due to elastic contraction, according to the formula:

$L_e = L \times T / M$, where $L_e$ = elongation due to stress T; M = 15,000,000 for copper; and L = length of span. With a subsequent increase in temperature however, the wire will become longer again, according to the relation;

$L = 100 \alpha t$, where $\alpha$ for copper is .0000096, and t = degrees F. temperature rise. That temperature that causes a sag equal to that under maximum condition of loading, and mimimum de-

grees temperature, is called the critical temperature rise equals $(T_c - T_o)$; $T_o = (-20)$. For various wires and conditions of loading, the following values have been taken from the curves on pp.181, "Still."

No wind and no ice.

| Cir mils. | Weight/span | T | $T_c - T_o$ | $T_c$ | %lag. |
|---|---|---|---|---|---|
| 500,000 | 465 | 5300 | 77 | 57 | 1% |
| 300,000 | 285 | 3560 | 90 | 70 | 1% |
| 4/0 B.S. | 195 | 1600 | 97 | 77 | 1.5% |
| Still | 170 | 1100 | 60 | 40 | 2% |

These values were claculated from the formula;

$$(t_c - t_o) = (t_1 - 8s^2 / C_2) + (C_3 \times (s_c/s - 1))$$

As this equation contains two unknown variables, sags equal to those under worst condition were assumed, to calculate critical temperature, $(t_o = -20)$ in this case, and corresponding tension in the wire. Of any other temperature, various values of sags were solved for in the formula, and the corresponding value $(t_c - t)$ obtained; from this, $t_c$ being known, the temper-

.

ature in degrees F. was obtained; and the curves plotted.

Sample Calculation.

For 500,000 circ. mils.

$t - t = (C_1 - 8s^2/C_2) + (C_3(S_c/S - 1))$; $t = 57$ deg.

$C_1 = 8s^2 \neq 72.$ $S_c = 3$ ft.

$C_2 = 3l \cdot a = 2.6$; $T = 5800$ lb. sq.

$C_3 = T/Ma = 40$;

For S $\neq$ 2ft.

$57 - t = (72 - 32)/2.6 + 40 \times 1.5 = 75°$

$t = 57 - 75 = -18°$

For S = 2.5 ft.

$57 - t = (72 - 8 \times 6.250)/2.6 + 40 \times ((3/2.50) - 1)$

$t = 57 - 16.5 = 40.5°$

The same calculations were carried thru for the other wires and the curves plotted giving temperature-sag relation. From this and the tension-sag curves as determined previously, the temperature-tension curves were obtained, to be used in stringing the wires. For the bare wires, the factor n for various wind velocities is practically unity and can be neglected.

## CATENARY CONSTRUCTION.

To keep the trolley wire horizontal and at a uniform height of 22 feet above the railheads, the double catenary suspension was found simple and effective. With 300 ft. spans a sag of 2%, or 6 ft, was found sufficient to keep the stress within safe limits at the assumed worst conditions of loading. To obtain a check on the calculated ordinates of the parabola, on which all calculations were based, a five brass chain was suspended between two supports at the same level and the deflections from the horizontal were measured and tabulated as follows: Sag of chain = 2% = 2x80/100 = 1.6" For parabola, $Y^2 = 2MX$; $M = 40^2/(2x1.6) = 500$, $Y^2 = 1000X$

| Distance ffom center of span | Ordinates | | Deflection as measured. |
|---|---|---|---|
| Y | X | 1.6 X | |
| 0 | .0 | 1.60 | 1.60 |
| 10 | .10 | 1.50 | 1.48 |
| 20 | .40 | 1.20 | 1.20 |
| 30 | .90 | .70 | .665 |
| 35 | 1.25 | .35 | .333 |
| 40 | 1.60 | .0 | .0 |

The resultant curve was drawn and the length of the hangers measured and expressed in feet as shown in the diagram. Fifteen hangers were used to support the middle wire from which, by thirty hangers, is suspended the contact wire, giving it a 3/4 inch sag at 50°F. for 10 ft. spans. The entire catenary system is electrically interconnected and suspended from the supporting structures by strain-insulators.

Loading of steel cable:

6/0 cable, breaking stress = 16,620 Lbs.

Resultant per ft., class B loading, 1.70 Lbs.

Total, 300x1.70 = 510 Lbs.

Resultant per ft. on 4/0 copper conductors = 1.641

Total, 600x1.641 = 1000 Lbs.

Resultant on Springers, 60', 60x1.641 = 100 Lbs.

Total loading on cable = 1610 Lbs.

From this, the tension in the cable is

$P_n = \frac{WL}{8S}$ = (1610x300)/(8x6) = 10,000 Lbs. which may be considered safe.

Temperature Sag for Steel Cable.

To allow an estimate of the vertical movement of the trolley with various temperatures without no load, as for the summer months for instance, the following calculations were made:

Crtical Temperature $E_2$ 57°

$S_c$ = 6' = 2%

M(Steel) = 25,000,000

$\alpha$ = .0000065

K = 430

$(T_c - T) = \frac{C_1 - 8S^2}{C_2} + C_3 \left(\frac{S_c}{S} - 1\right)$ $C_1 = 8.5 = 310$

$C_2 = 1.30$

$C_3 = 17.0$

for S = 7: $(T_c - T) = \frac{310-390}{1.8} + (17.01) = -(45 + 1.6)$; T=103°

for S = 5: $(T_c - T) = \frac{310-200}{1.8} + (1.7\ 1.25) = 63$; T = 6°

This shows that for a maximum temperature range of 110° a vertical movement of one ft. from normal is to be expected.

Loading on Line Support:

(1) Vertical component.

Take the heaviest loaded section, the one carrying the 500,000 cir. mils conductors; one half only of the supporting structure will be considered as the arrangement is symmetrical and each supporting column shares one half the load.

| | | |
|---|---|---|
| (A) 500,000 C.M. Copper Conductor | Max. Weight per Span 700 | Lbs. |
| " " " " " | 700 | " |
| " " " " " | 700 | " |
| 3 Suspension type insulators ice or snow @ 45 Lbs. | 135 | " |
| Steel Protection cable, 00, | 90 | " |
| | 2325 | " |
| (B) Weight of Catenary System | | |
| Messenger cable, @ 1.238 | 370 | Lbs. |
| 2 Insluators, @ 20 Lbs. | 40 | " |
| Stringers, 60' @ 1.286 | 77 | " |
| 2 4/0 Copper Cond. @ 1.286 | 770 | " |
| | 1257 | " |
| Total Lbs. | 3582 | " |

(2) Horizontal Component, transverse to line.

| | |
|---|---|
| 3 x 500,000 C.M. Copper Cond., @ 1.313 | 1100 Lbs. |
| 3 Insulators, | 15 " |
| Steel protecting cable, 300 x 1.16 | 350 " |
| Catenary structure | 980 " |
| Total Lbs. | 2445 " |

(3) Horizontal Component, parallel to line.

| | |
|---|---|
| Pull in 500,000 C.M. Copper Cables | 30,000 Lbs |
| " " 2/0 Steel protecting Cable | 640 " |
| " " Catenary messenger Cable | 10,000 " |
| Endstress, total, on anchorbridge | 40,640 " |

# PART 8.

## DESIGN OF POWER PLANT

A. The boiler-house.

Steam is generated at 200 Lbs. pressure from twenty-four 1000 horse power units of B.& W. boilers, arranged in three double rows. Feed water is supplied through concrete conduits and pumped through feed water heaters into the boilers by multiple stage centrifugal pumps driven by small steam turbines.

Mine run coal is furnished to the coal hoppers from which the crushers are supplied; these empty into the endless conveyors which fill the overhead coal bunkers at the boilers. The coal is burnt on chaingrates and the ashes, as well as the fine unburnt coal falling through the grate, are stored and removed at intervals by the same endeless conveyor supplying the coal bunkers; the unburnt coal is collected at the time the coal bunkers are supplied, while the ashes are collected during the intervening time and dumped into the ash-storage bin, located right over the railway tracks; a swing spout operates the ash valve which allows easy filling of the cars; a water spraying arrangement is provided

4. The water-room.

to keep down the dust.

B. The Generating Plant.

Eight horizontal Westinghouse turbo-generator sets are provided of the following cacpacity;

Two units of 20,000 KW = 40,000 KW

Four units of 12,500 KW = 50,000 KW

Two units of 10,000 KW = 20,000 KW

The turbines exhaust into condensers located in the basement, or through the atmospheric relief valve into the opeh air exhaust; circulating water is taken from the concrete conduits by centrifigal pumps located in the basement between the turbine foundations.

100,000 KWA at 11,000 volts are delivered to the station buses. The generator leads are run through the basement to motor operated oil switches and so arranged to connect any alternator either to the bus or direct to its transformer, then through a high tension oil switch, to the 66,000 voltbuses on the second gallery.

The entire installion is controlled from a bench board on the first gallery overlooking the

turbine floor.

The controll apparatus in energized from 110 volts D.C. Power buses which are supplied by two turbine driven D.C. generators. Normally the alternators furnish their own field excitation, but they also can receive their exciting current from these D. C. buses through a hand operated double pole double throw switch. Both the field rheostats and the turbine governors are motor operated and controlled from the gallery; limit switches and signal lamps safe guard the controll apparatus. Inverse time limit overload relays protect the generators and give the warning to the operator before the breakers open.

Outdoor alluminum lighting arresters of G.E. design prevent surges and high frequency ascillations from reaching the station apparatus.

The sub-stations will consist of four 3800 KVA outdoor type single phase transformers as manufactured by the Westinghouse Electric & Manufacturing Company; lighting arresters on the roof of the station building will furnish protection on the

line side, while time limit overload relays, set for a shorter period than those in the central station, guard against trouble from the trolley side.

## APPENDIX.

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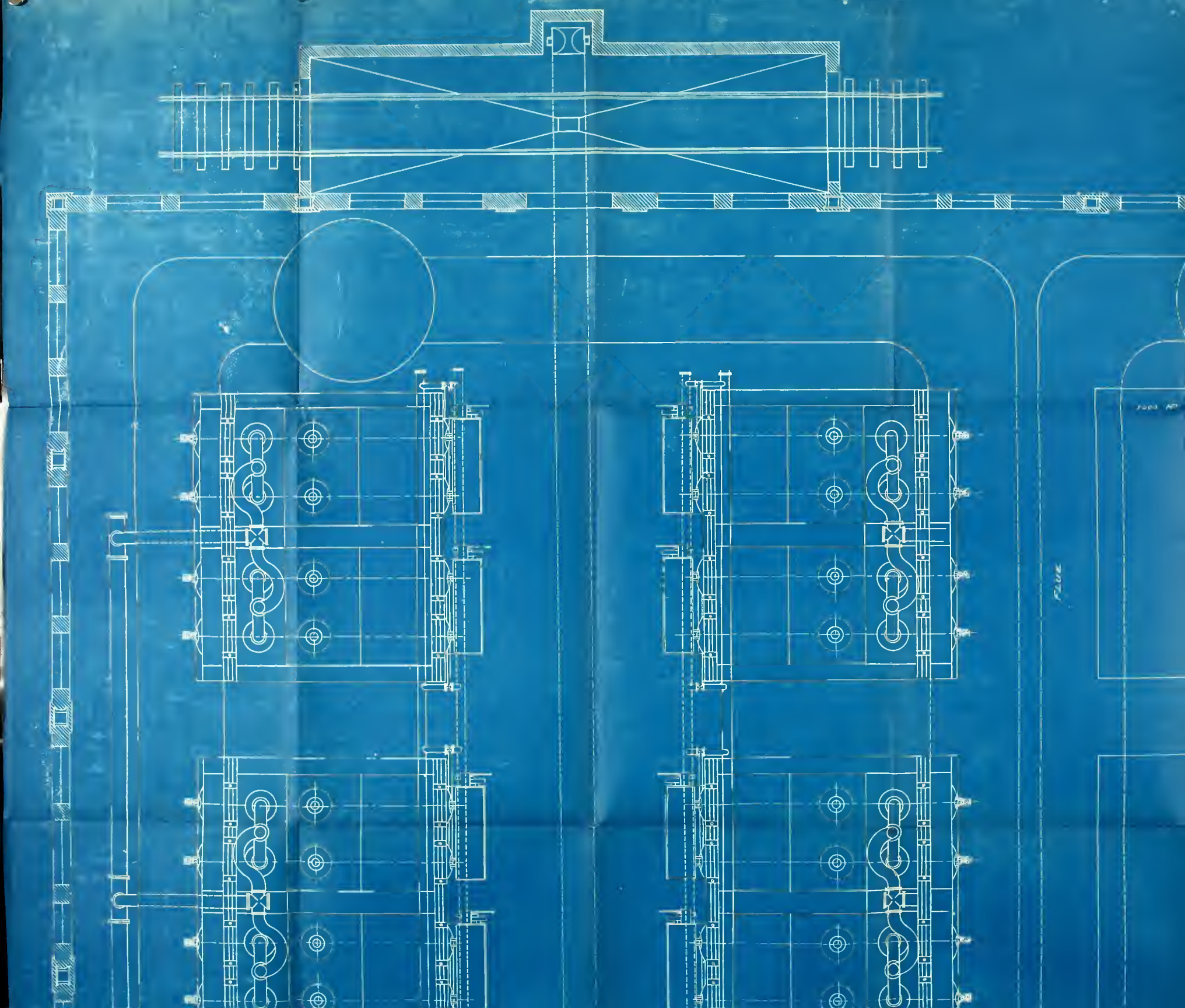
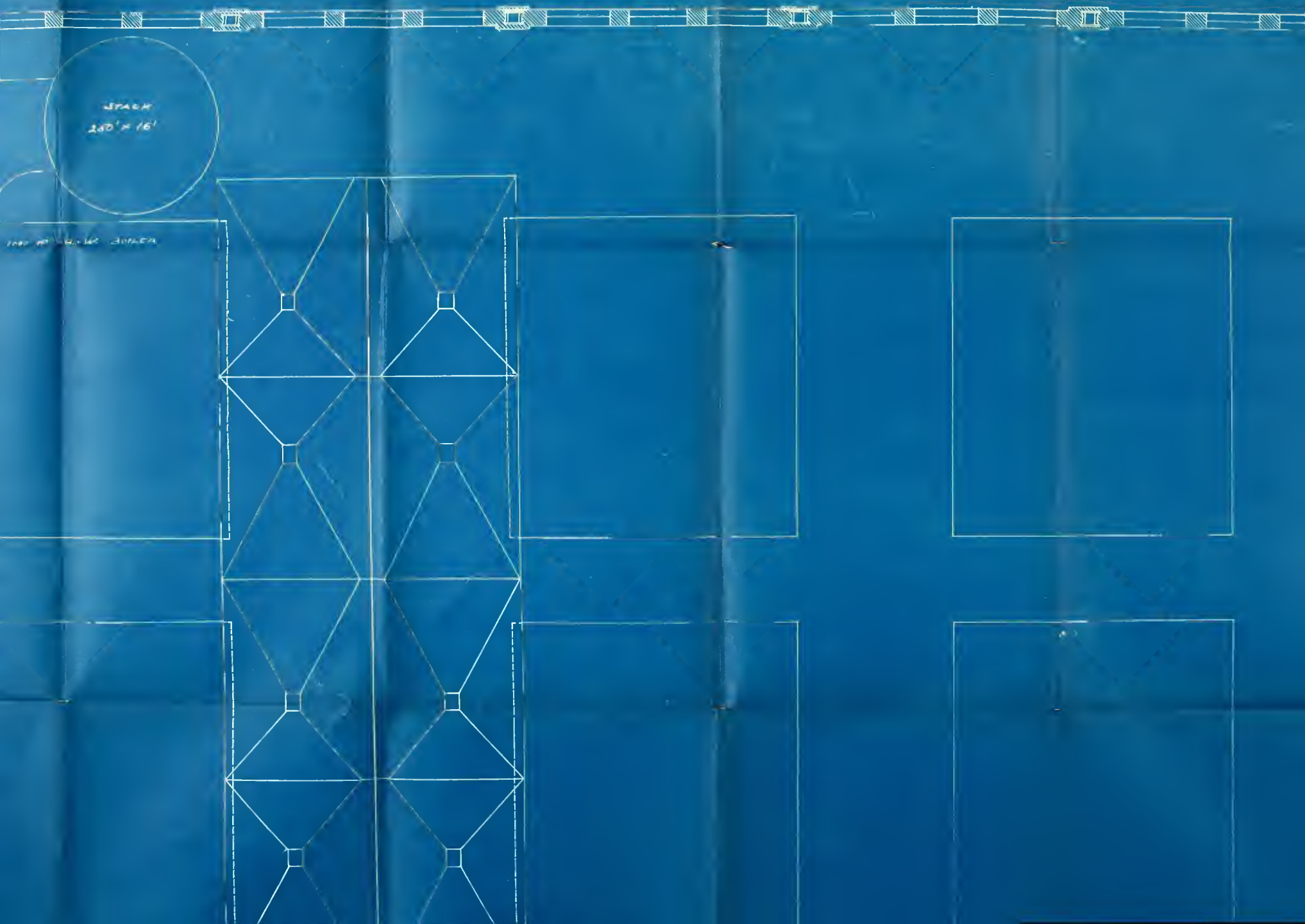


PLAN of POWER PLANT for

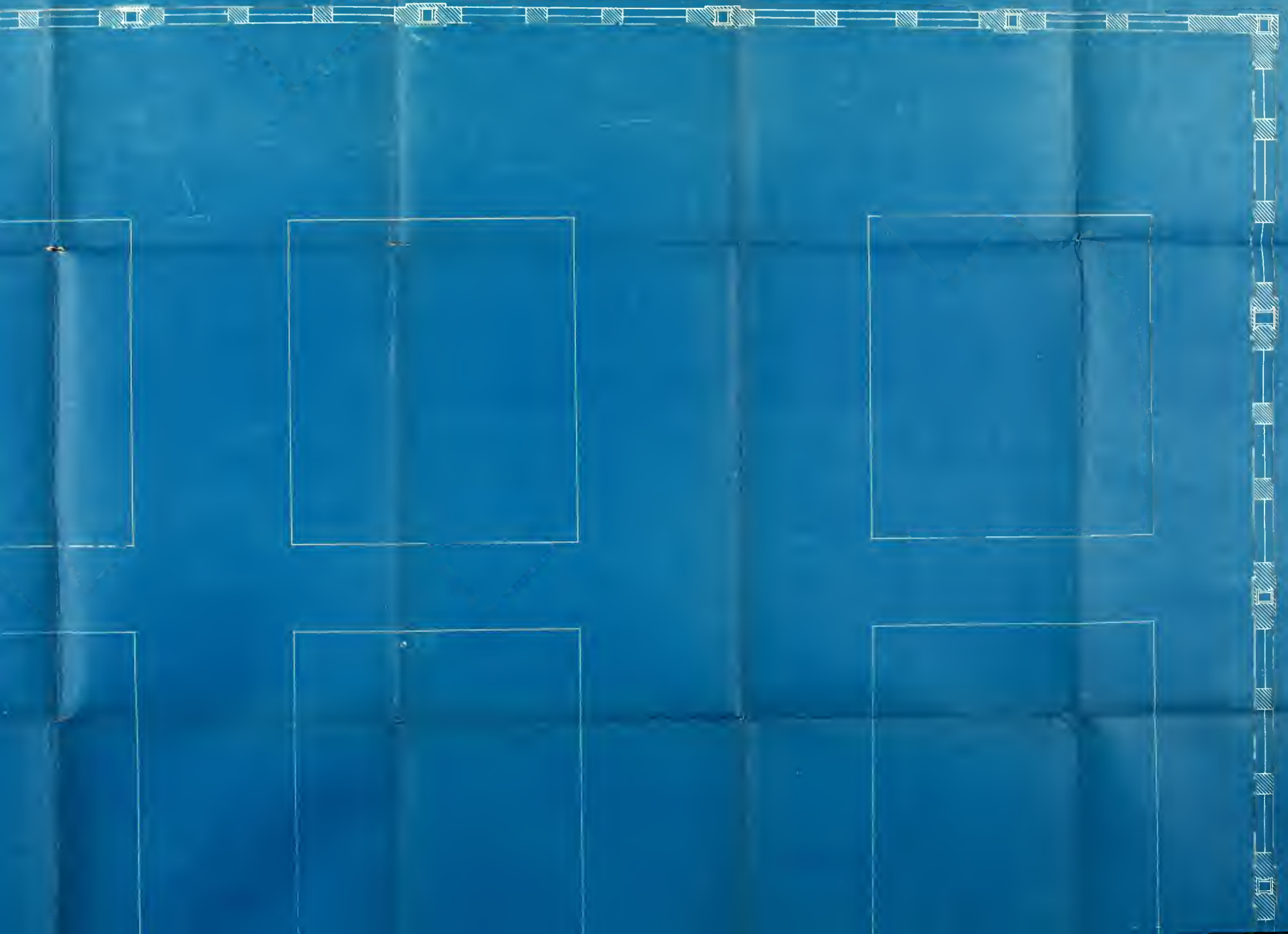
# PROPOSED ELECTRIFICATION of CHICAGO BRANCH-I.C.R.R.

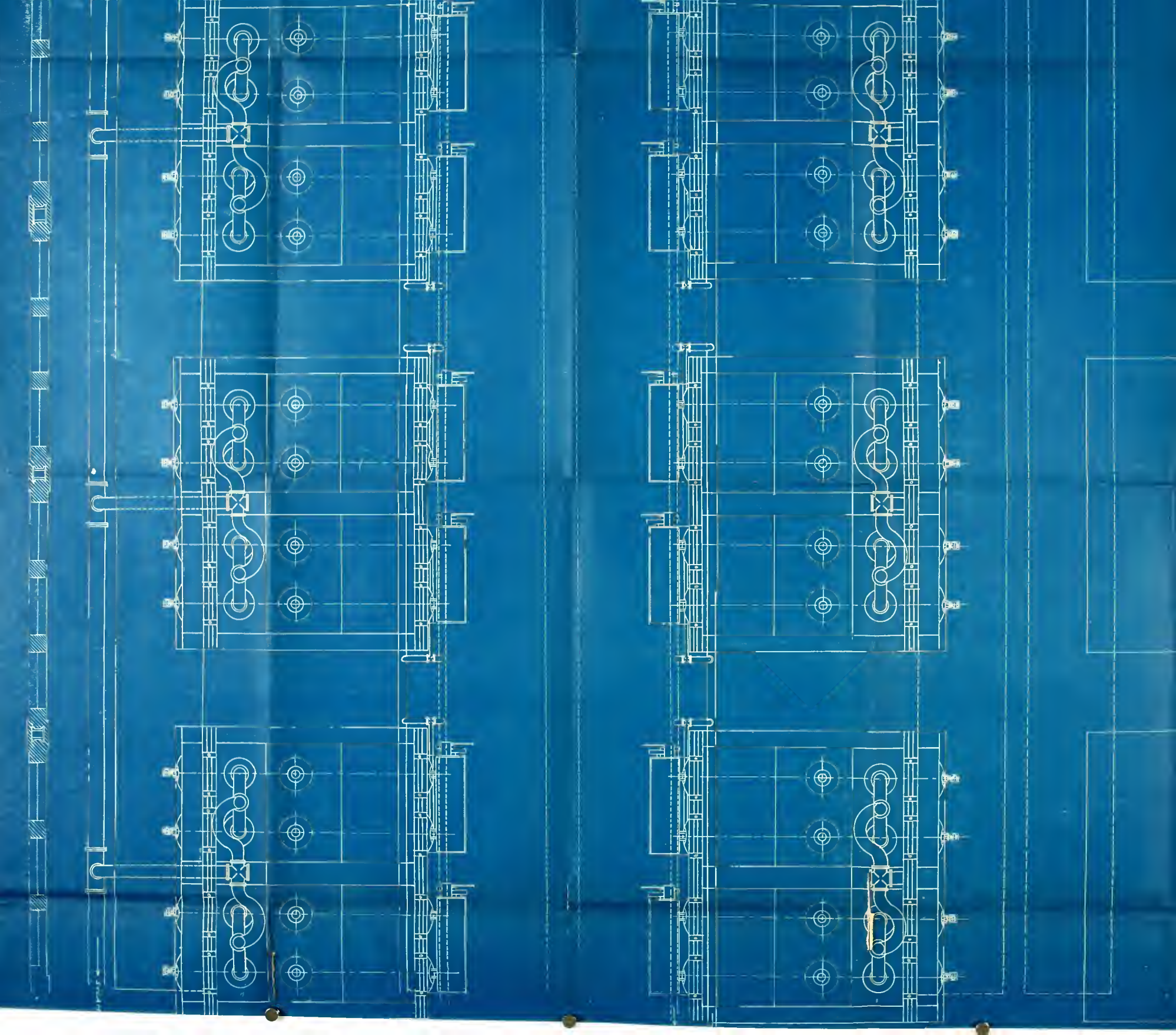
ARMOUR INSTITUTE of TECHNOLOGY

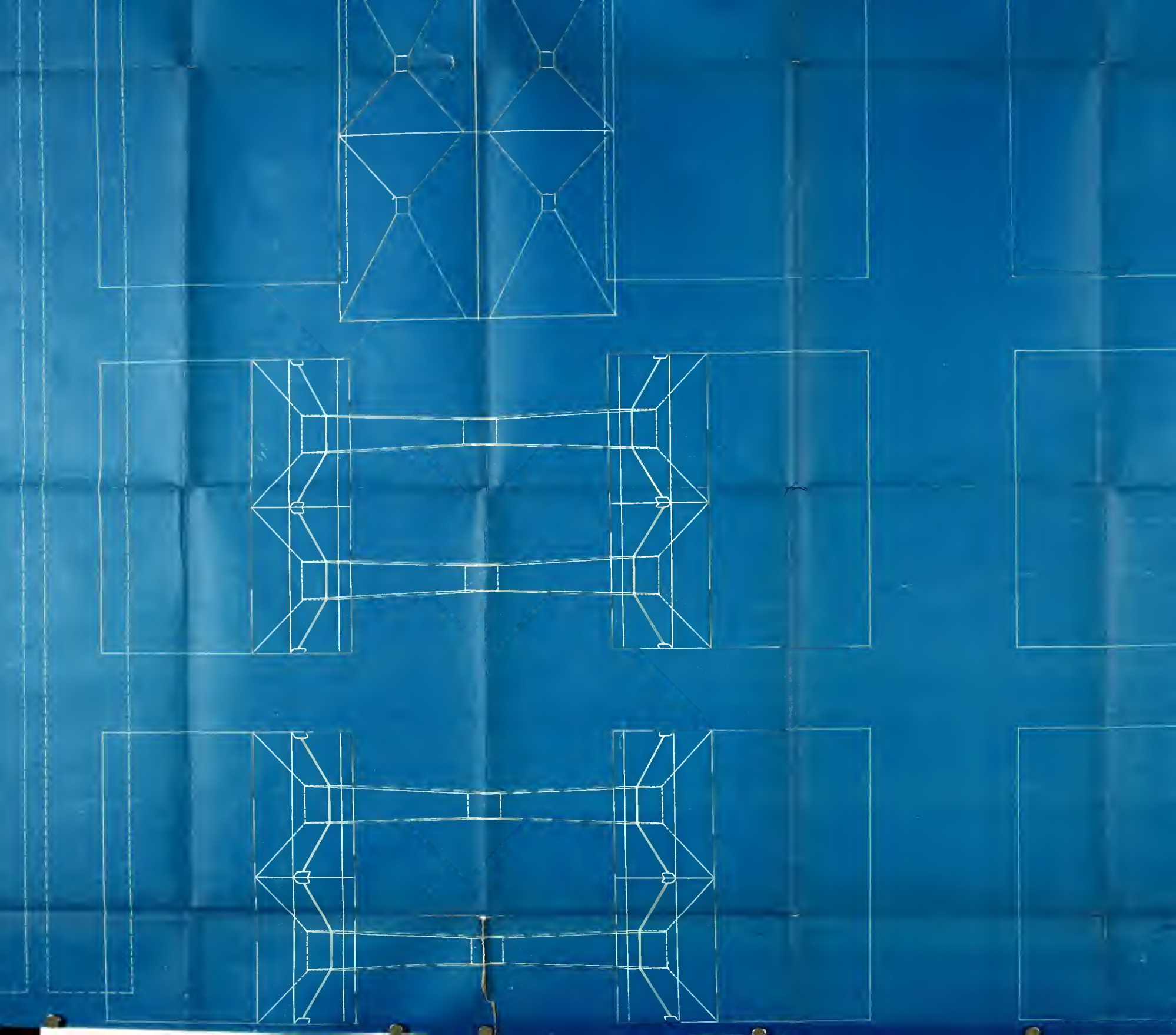
MAY 1916 CHICAGO ILL.

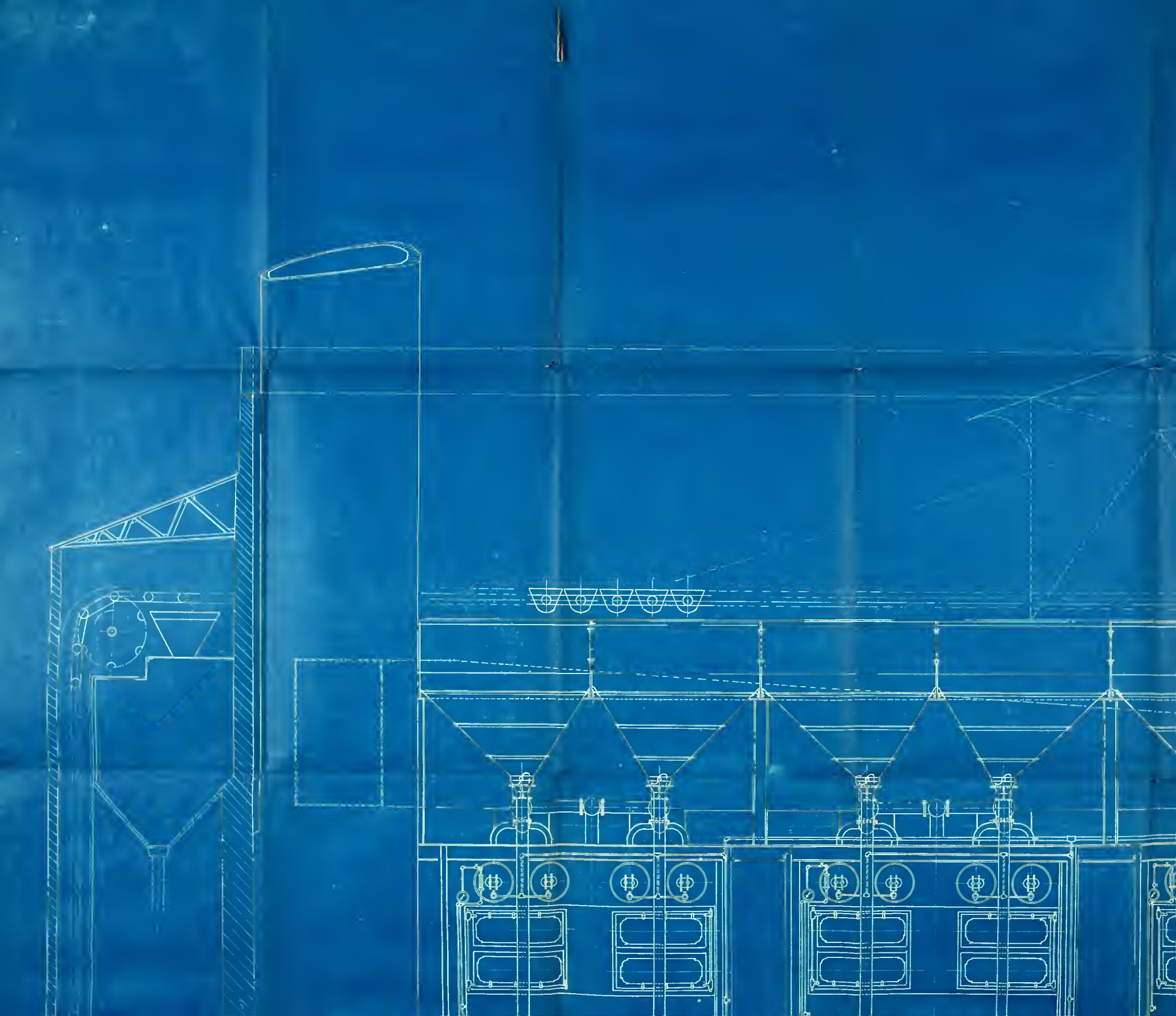


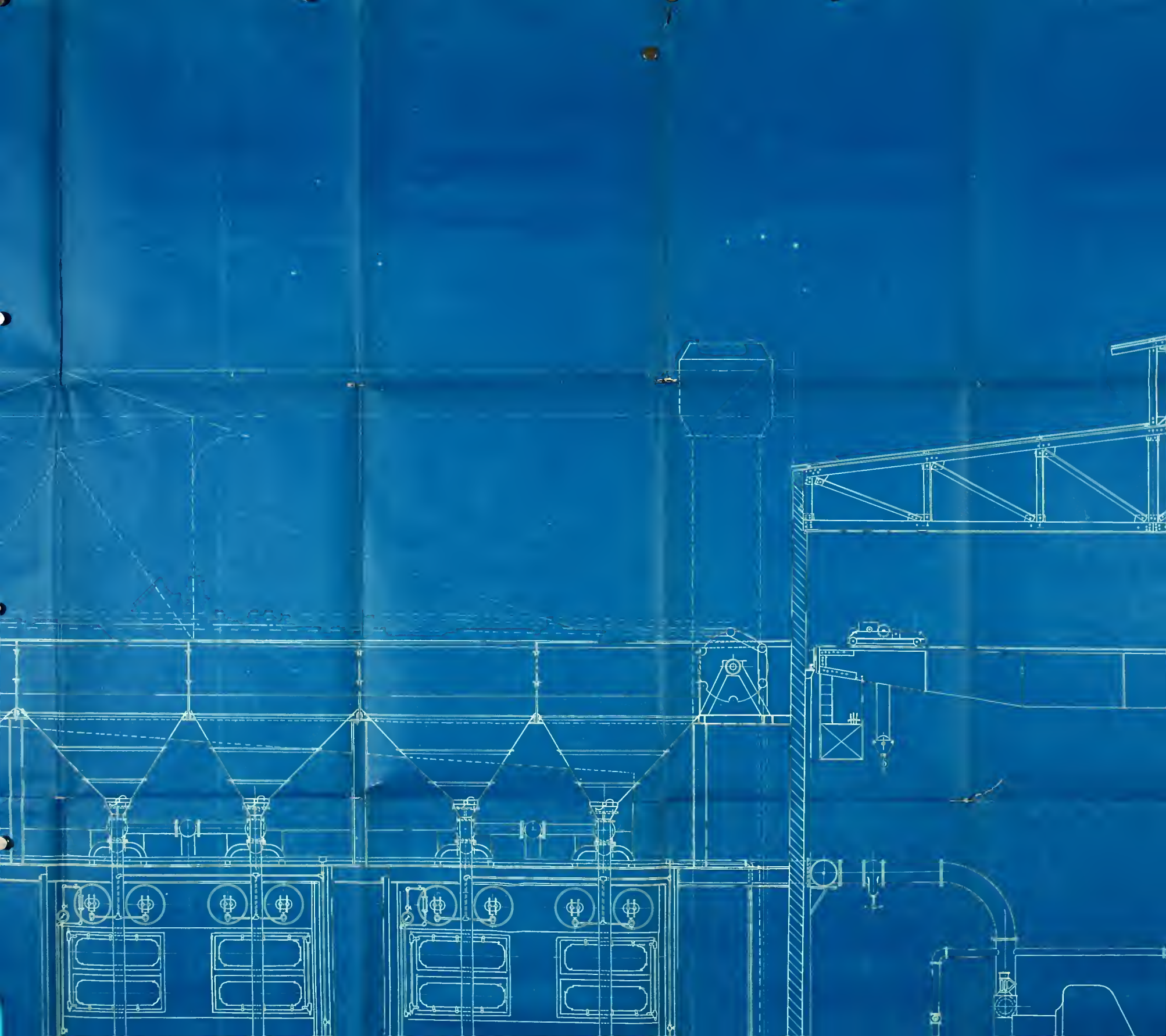
I. G. R. R.

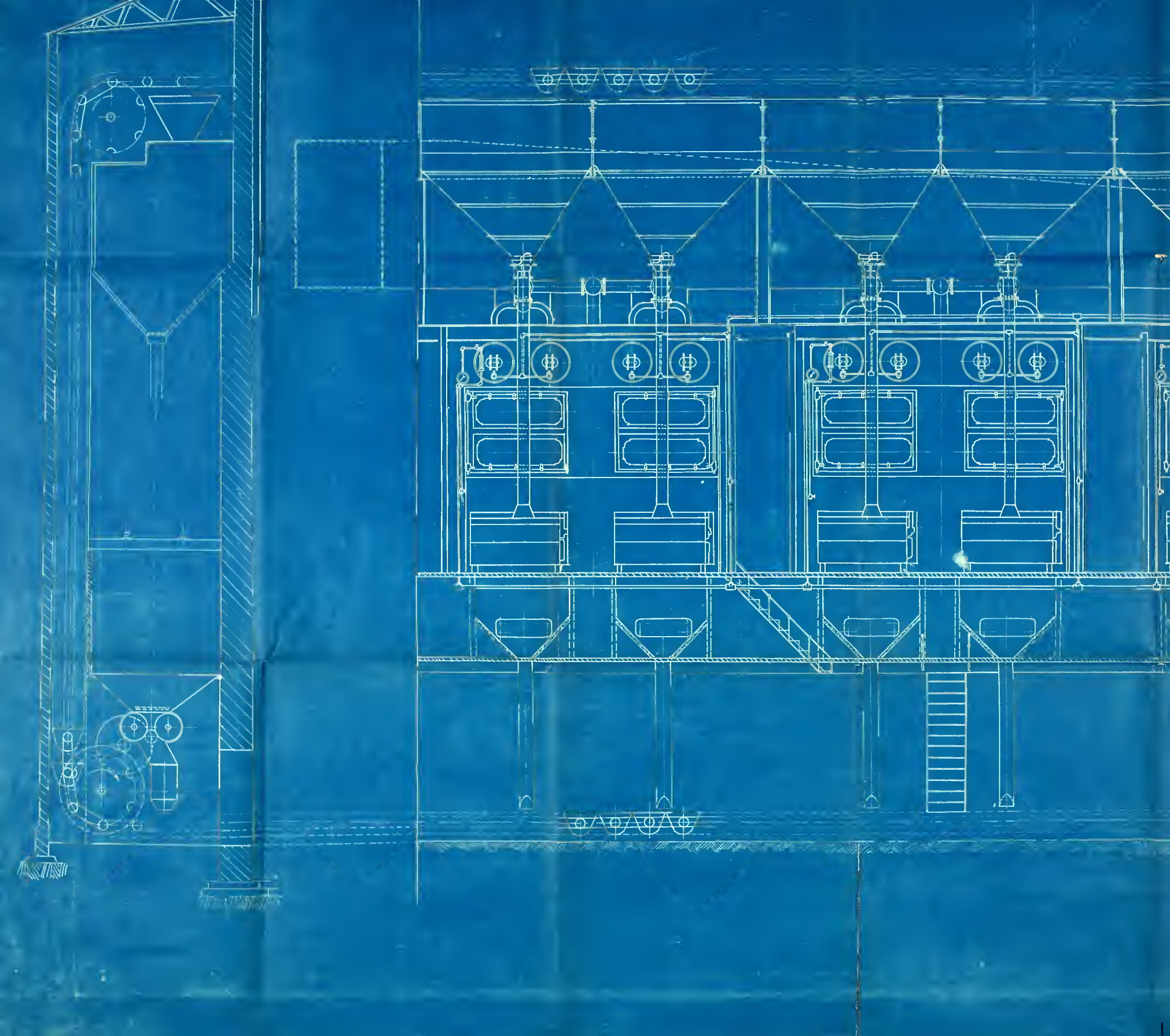


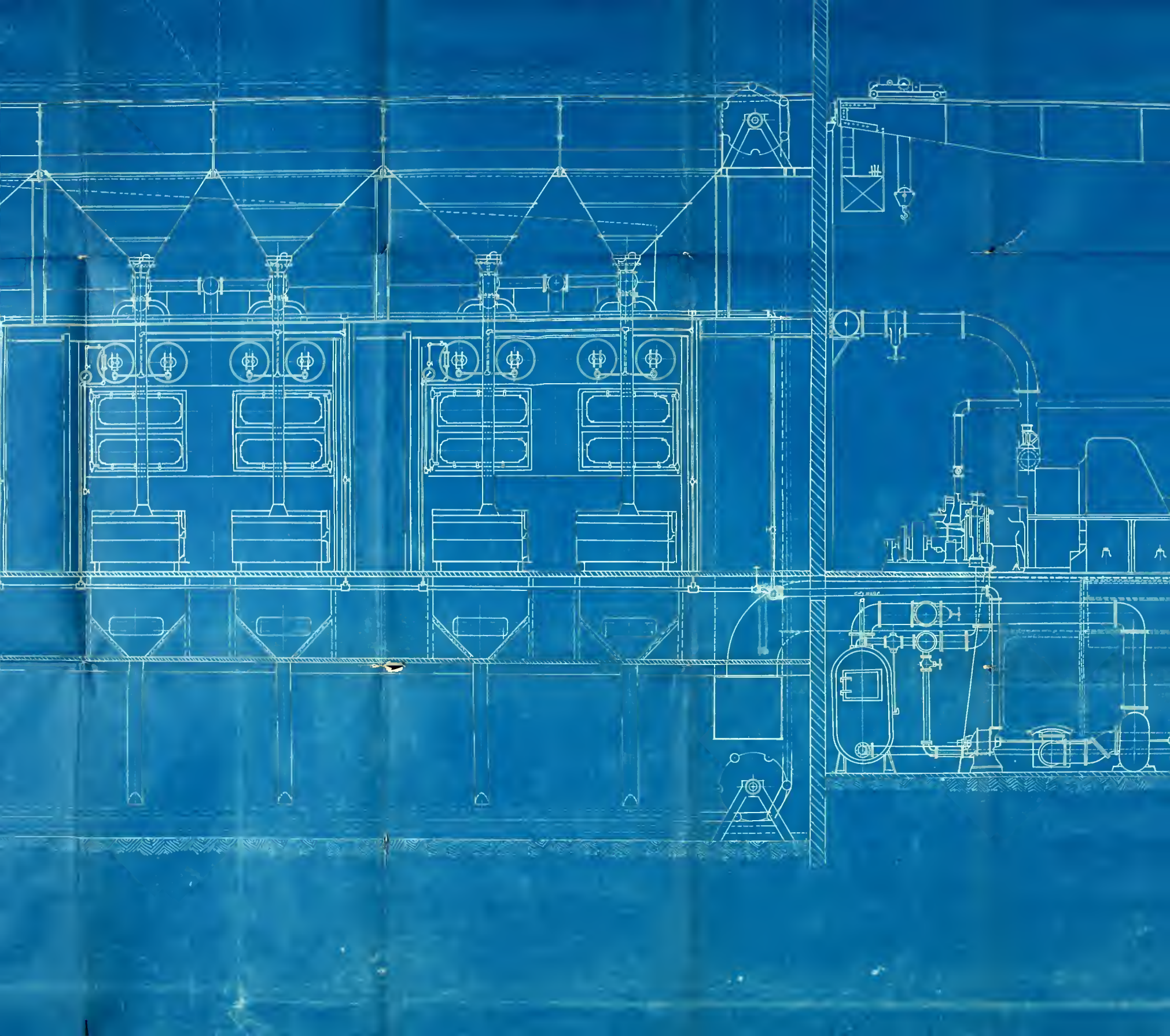


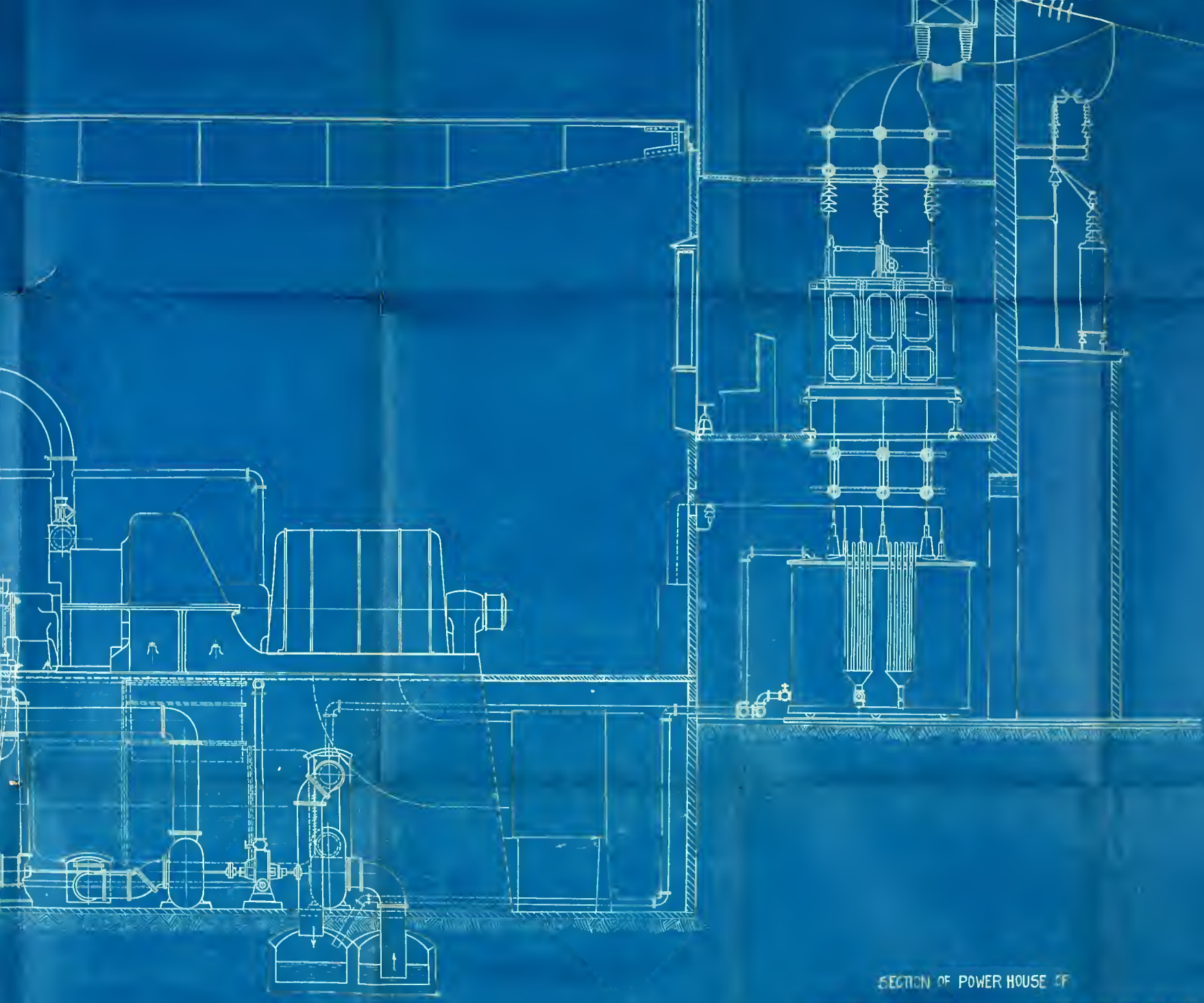












SECTION OF POWER HOUSE OF

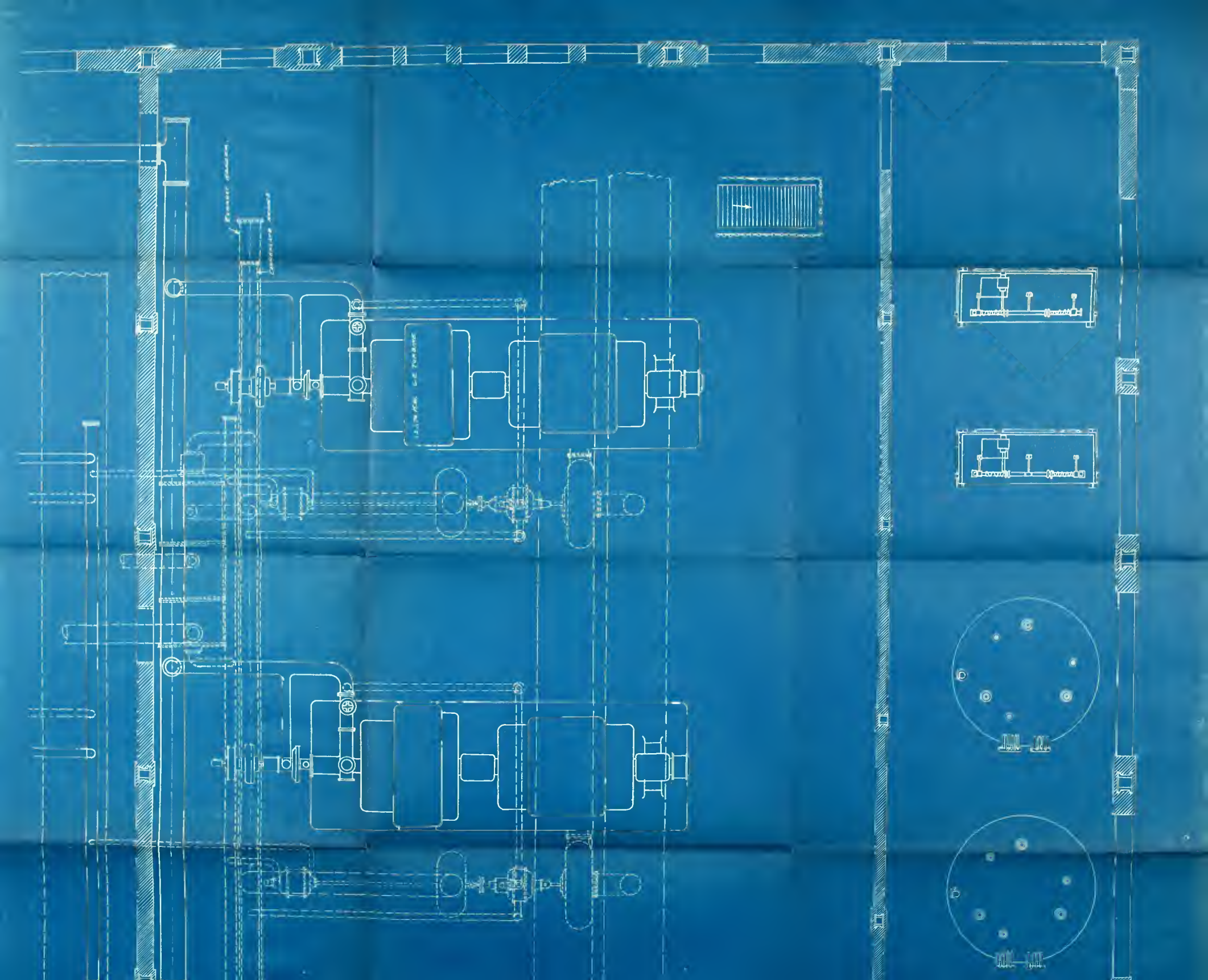
PROPOSED ELECTRIFICATION OF CHICAGO-ST LOUIS BRANCH

OF THE I.C.R.R.CO. AT CLINTON, ILL.

ARMOUR INSTITUTE OF TECHNOLOGY

MAY 1916 CHICAGO, ILL.

C.C. Wood.



PROPOSED ELECTRIFICATION OF CHICAGO BRANCH OF I.C.R.R.

ARMOUR INSTITUTE OF TECHNOLOGY

CHICAGO, ILL.

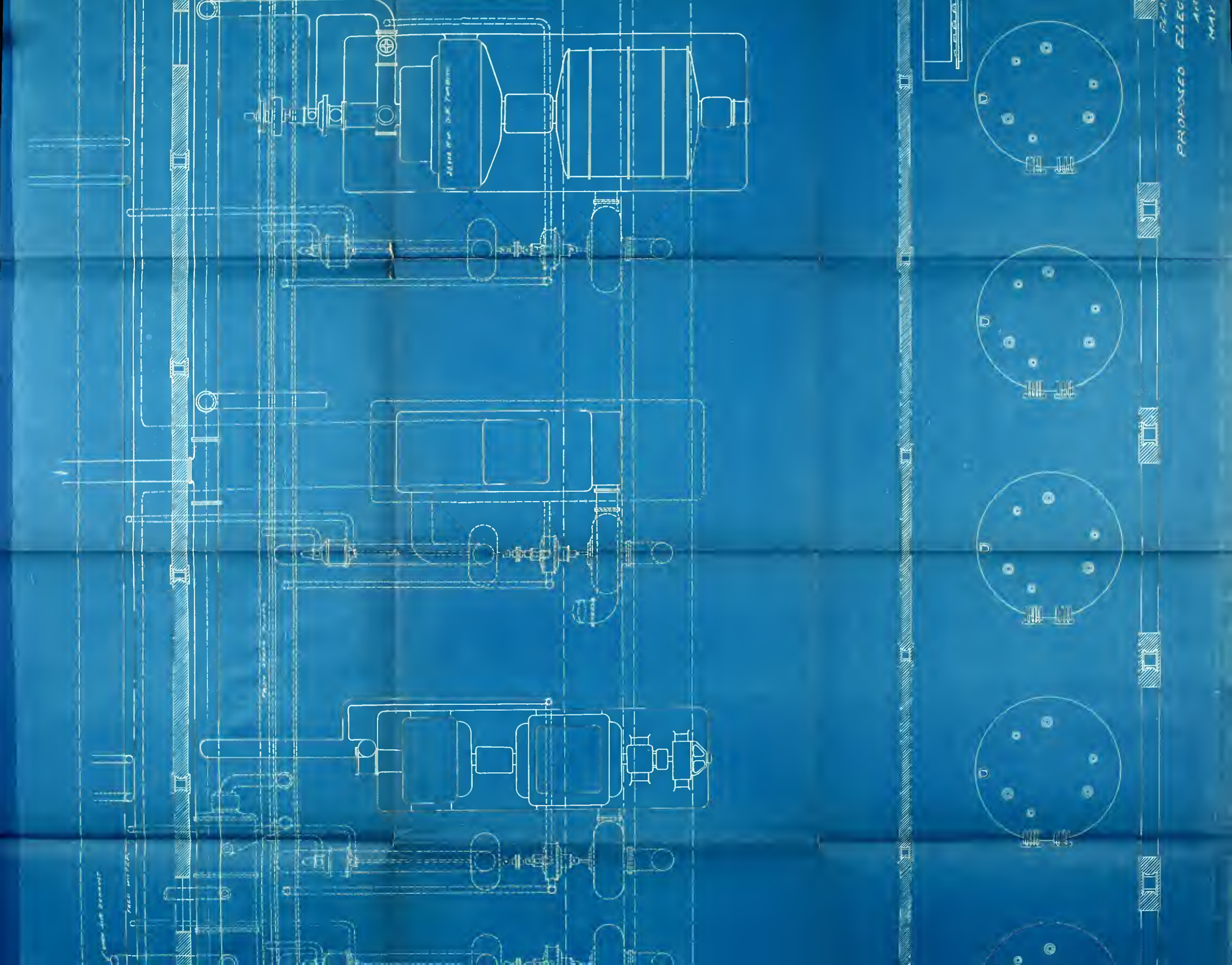
MAY 1926

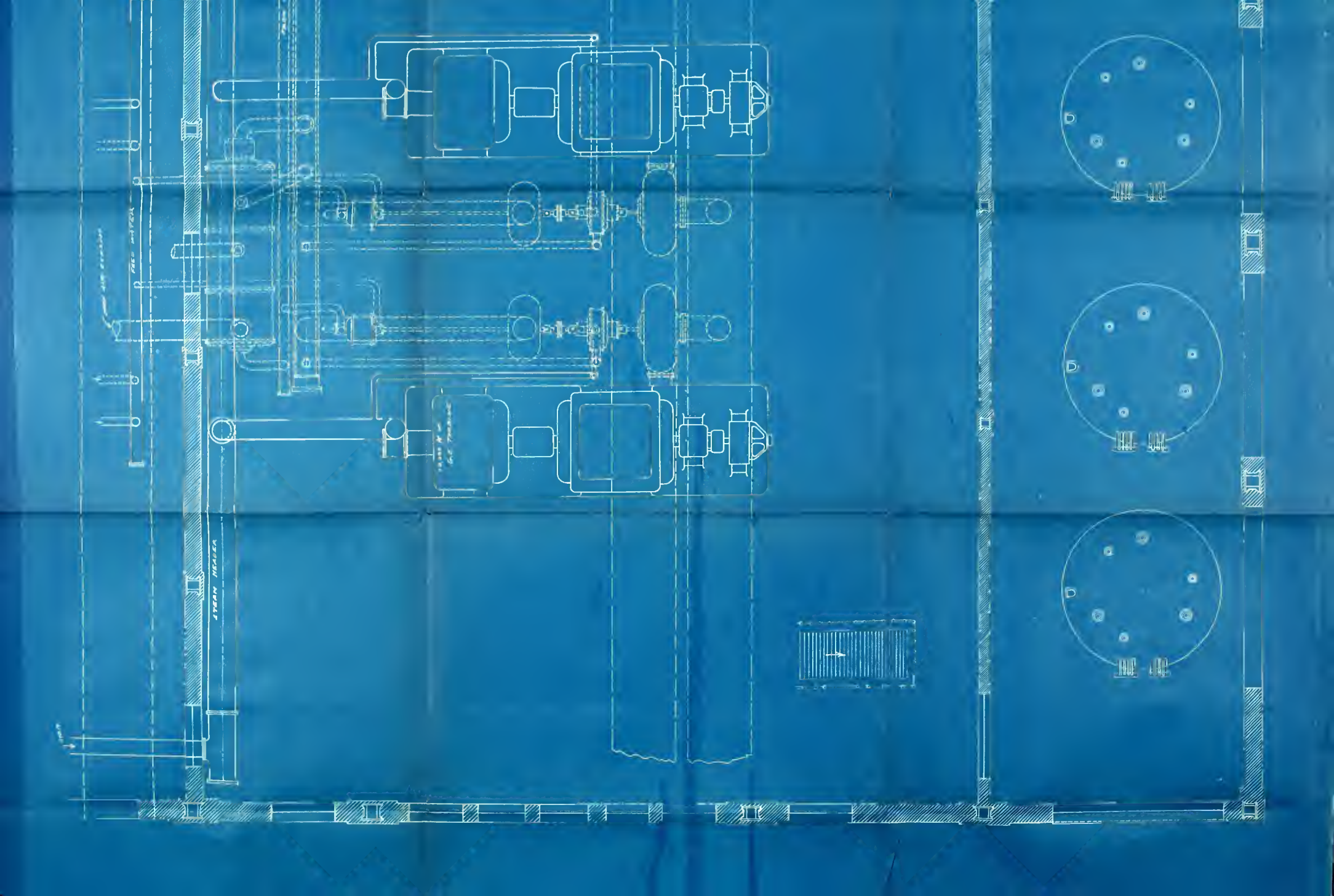
PLAN

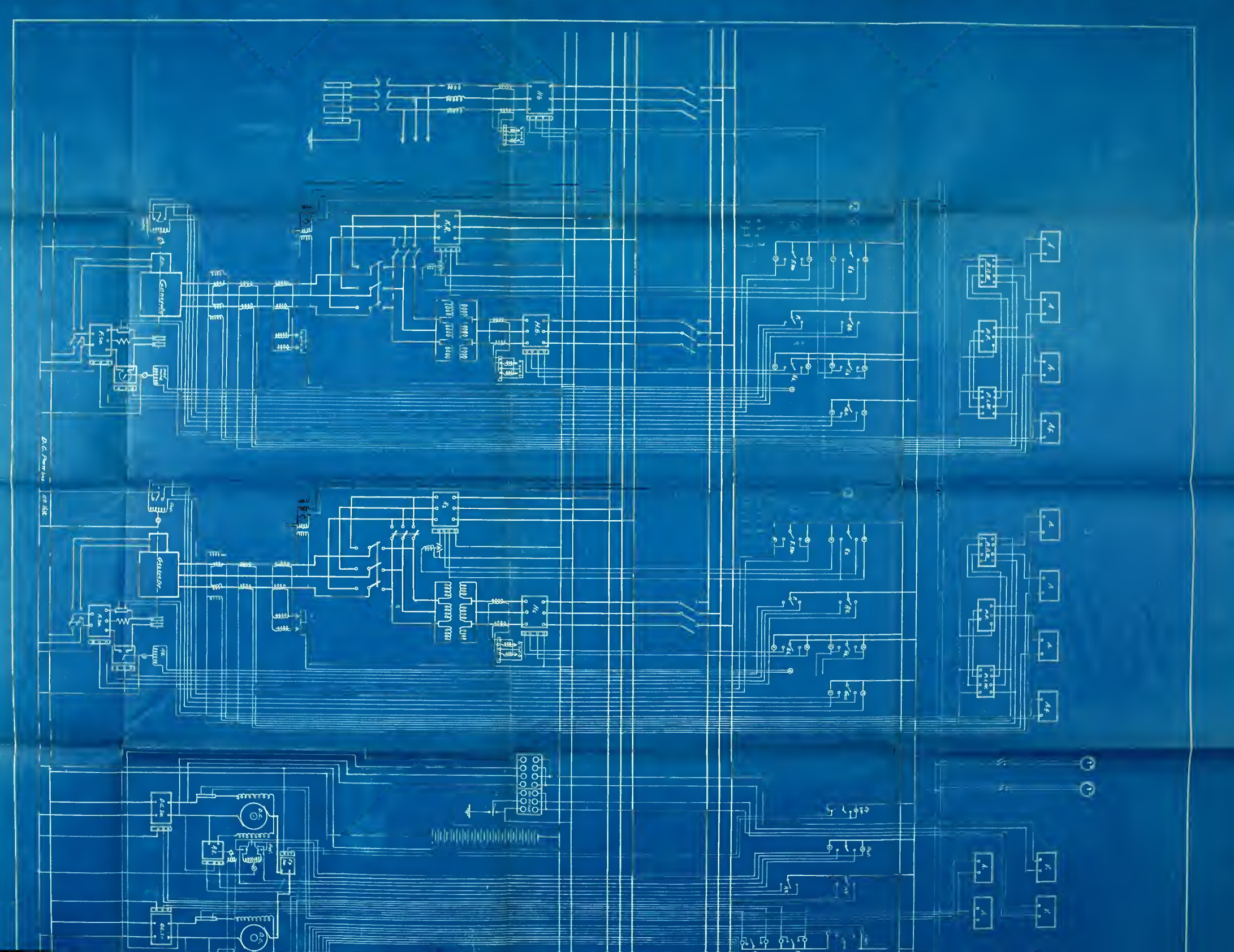
HEATER

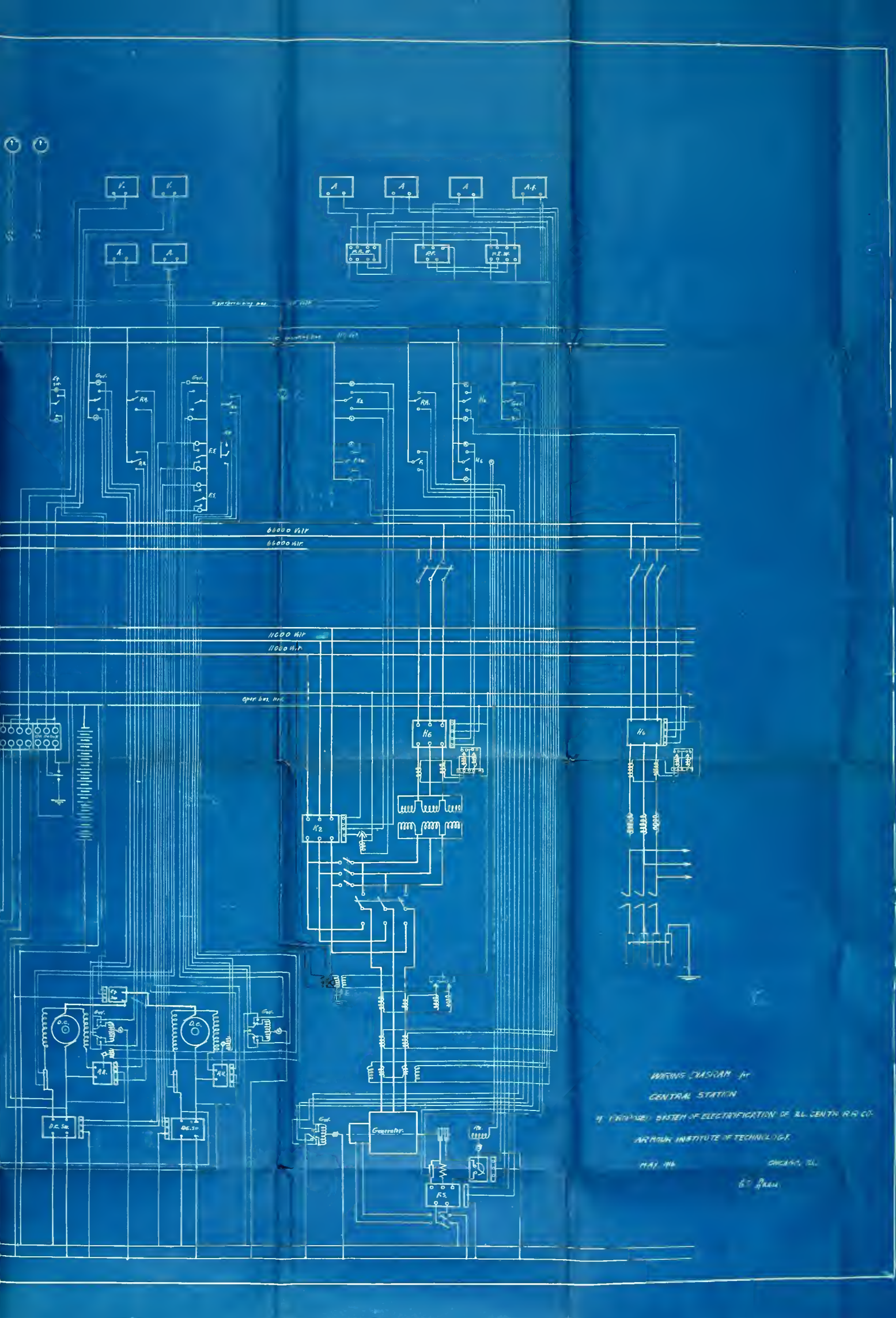
TO CITY MAINS

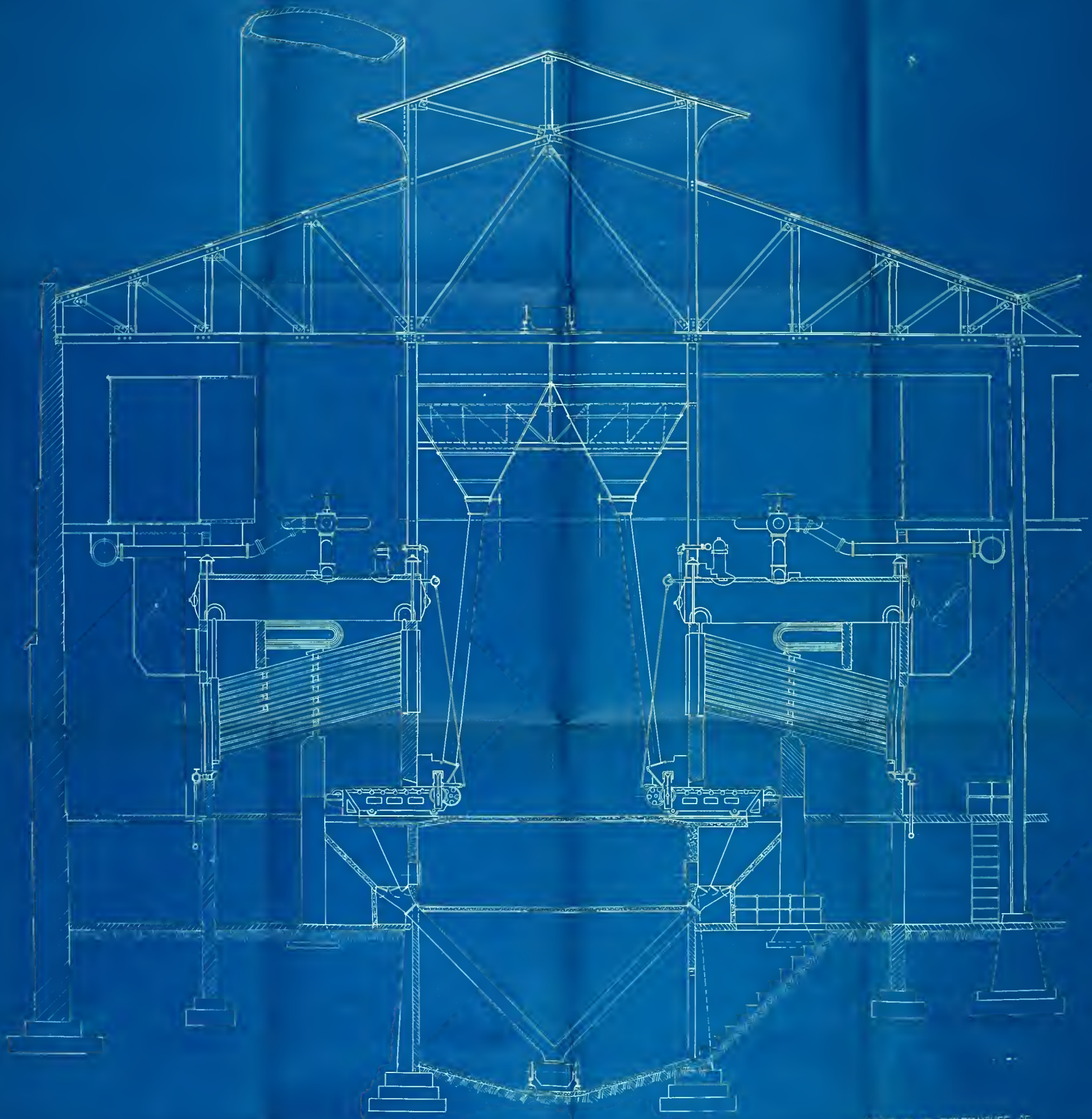
ARMATURE COILS




FEED WATER
STEAM HEADER




66000 Volt
66000 Volt
11000 Volt
11000 Volt
Controller
WIRING DIAGRAM for
CENTRAL STATION
of PROPOSED SYSTEM OF ELECTRIFICATION OF ILL. CENTRAL R.R. CO.
ARMOUR INSTITUTE OF TECHNOLOGY.
MAY 1916
CHICAGO, ILL.
G.T. Rhea



SECTION OF BOILER HOUSE "F"

PROPOSED ELECTRIFICATION OF CHICAGO-ST LOUIS BRANCH

OF THE I.C.R.R.CO., AT CLINTON, ILL.

ARMOUR INSTITUTE OF TECHNOLOGY

MAY 1916

CHICAGO ILL.

C.H. Morris.

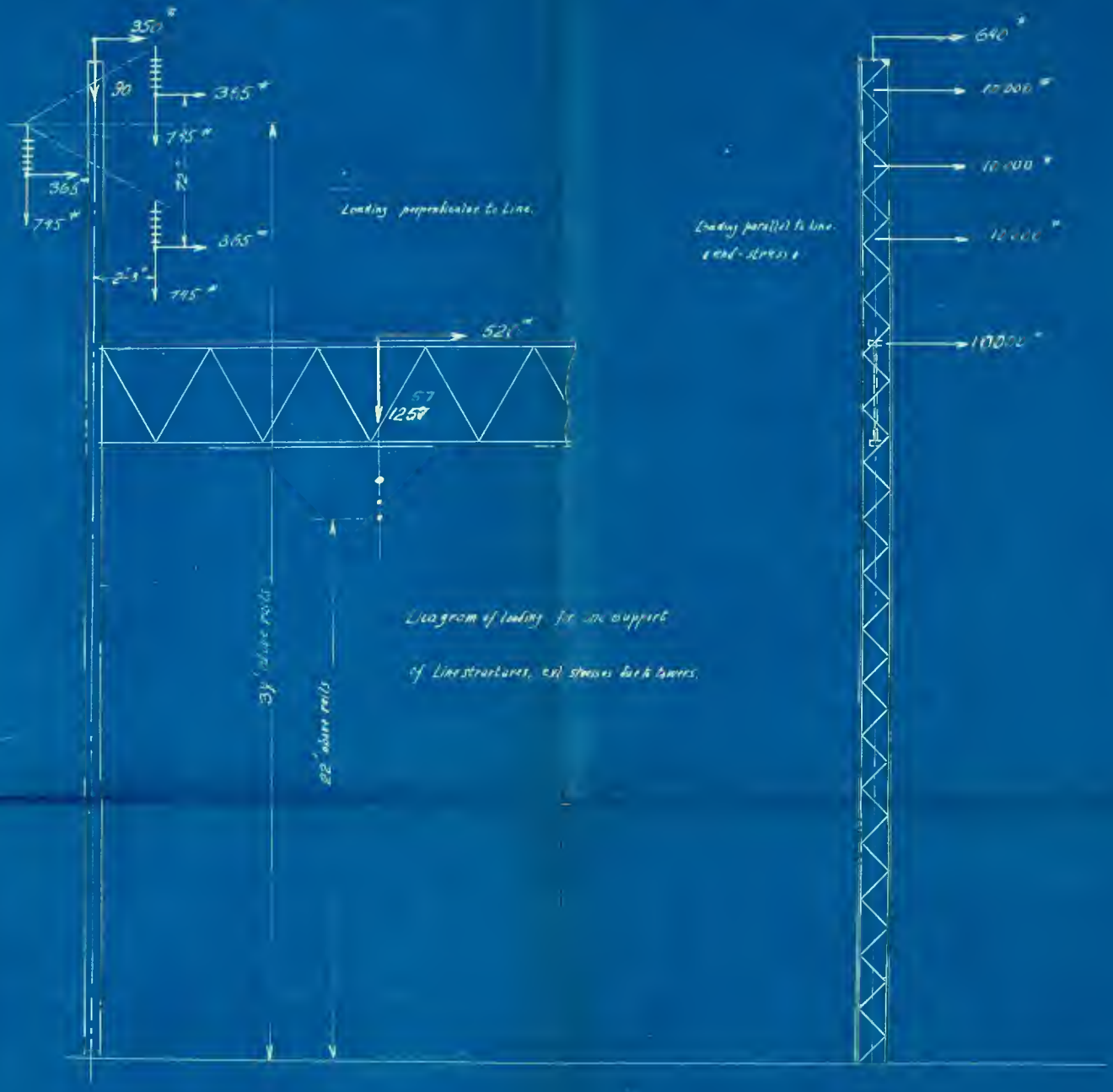



Diagram of loading for one support of Line Structures, end stresses due to towers.

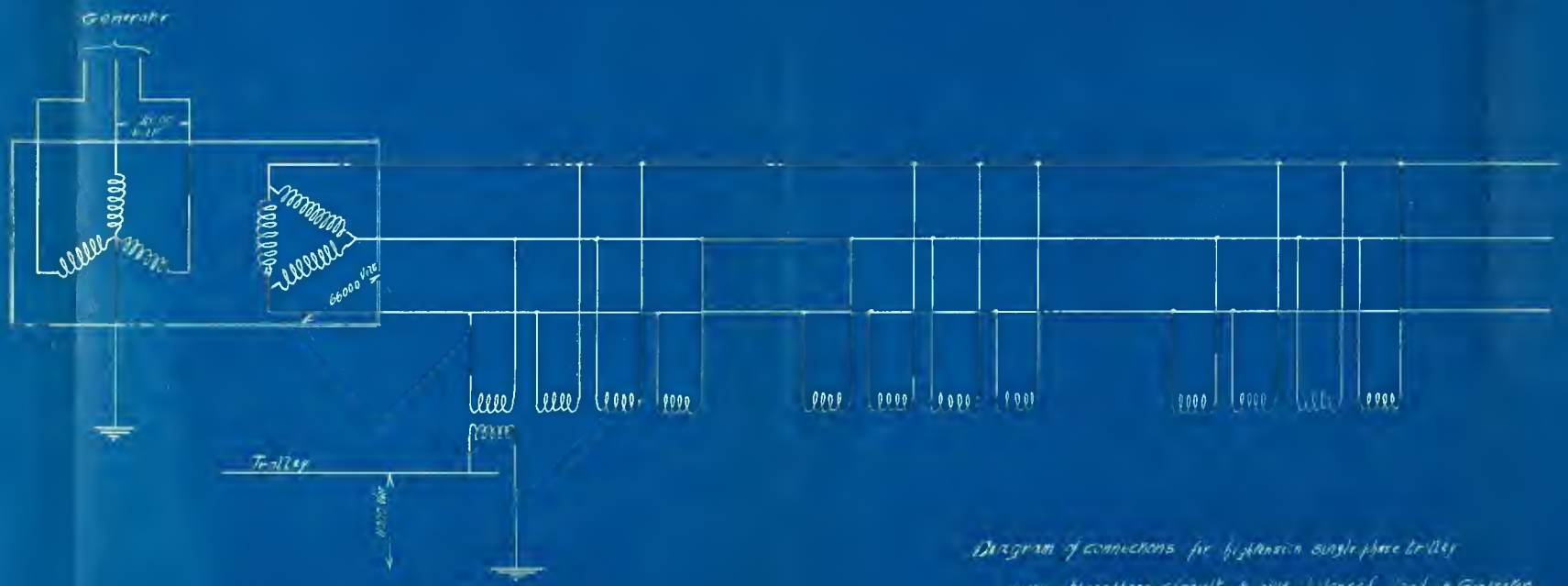
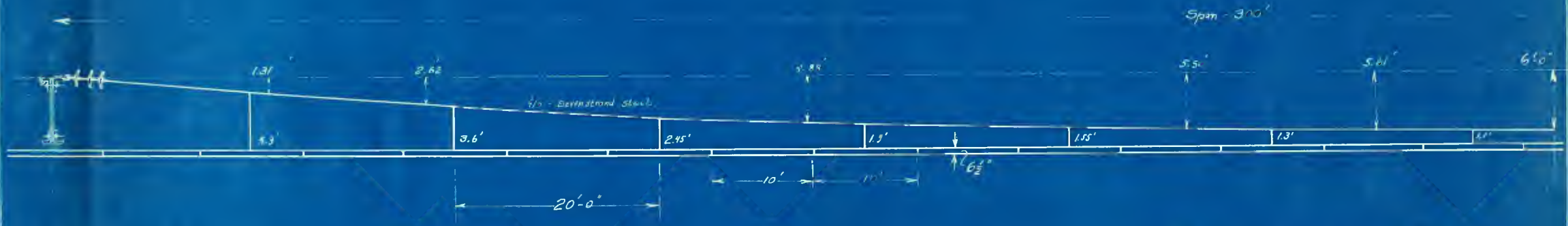
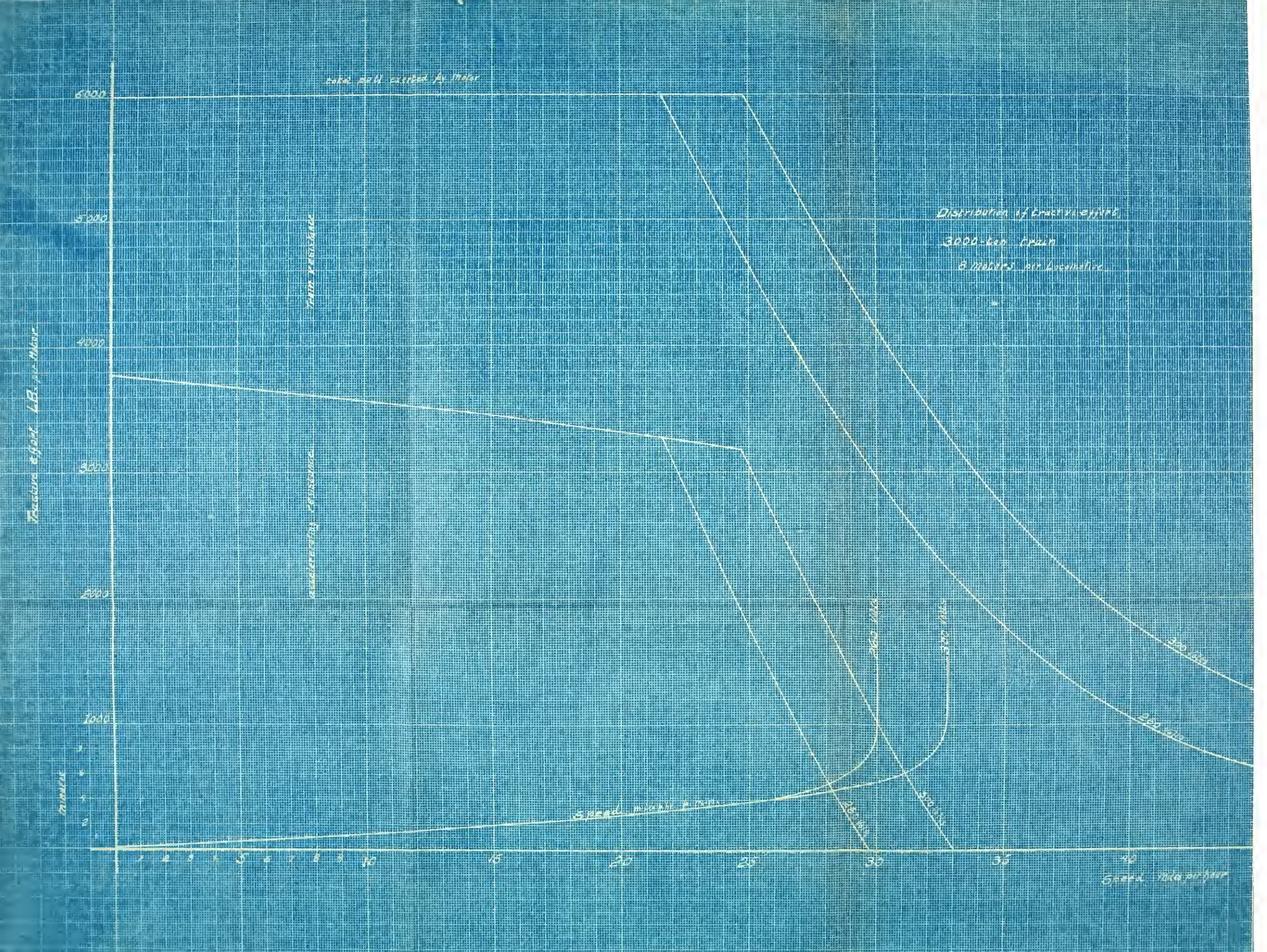


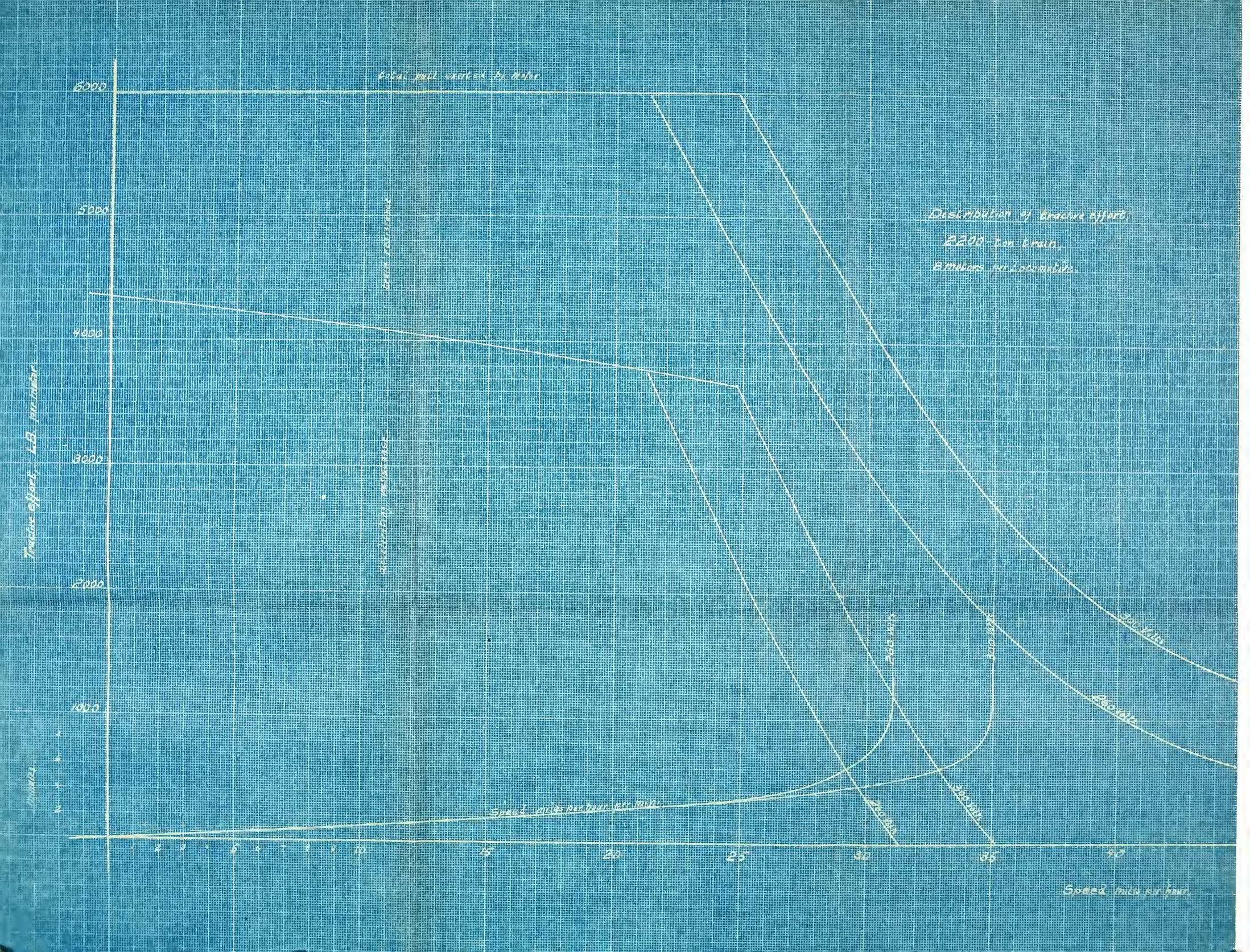

Diagram of connections for high tension single phase trolley from three phase circuit to give balanced load on Generator

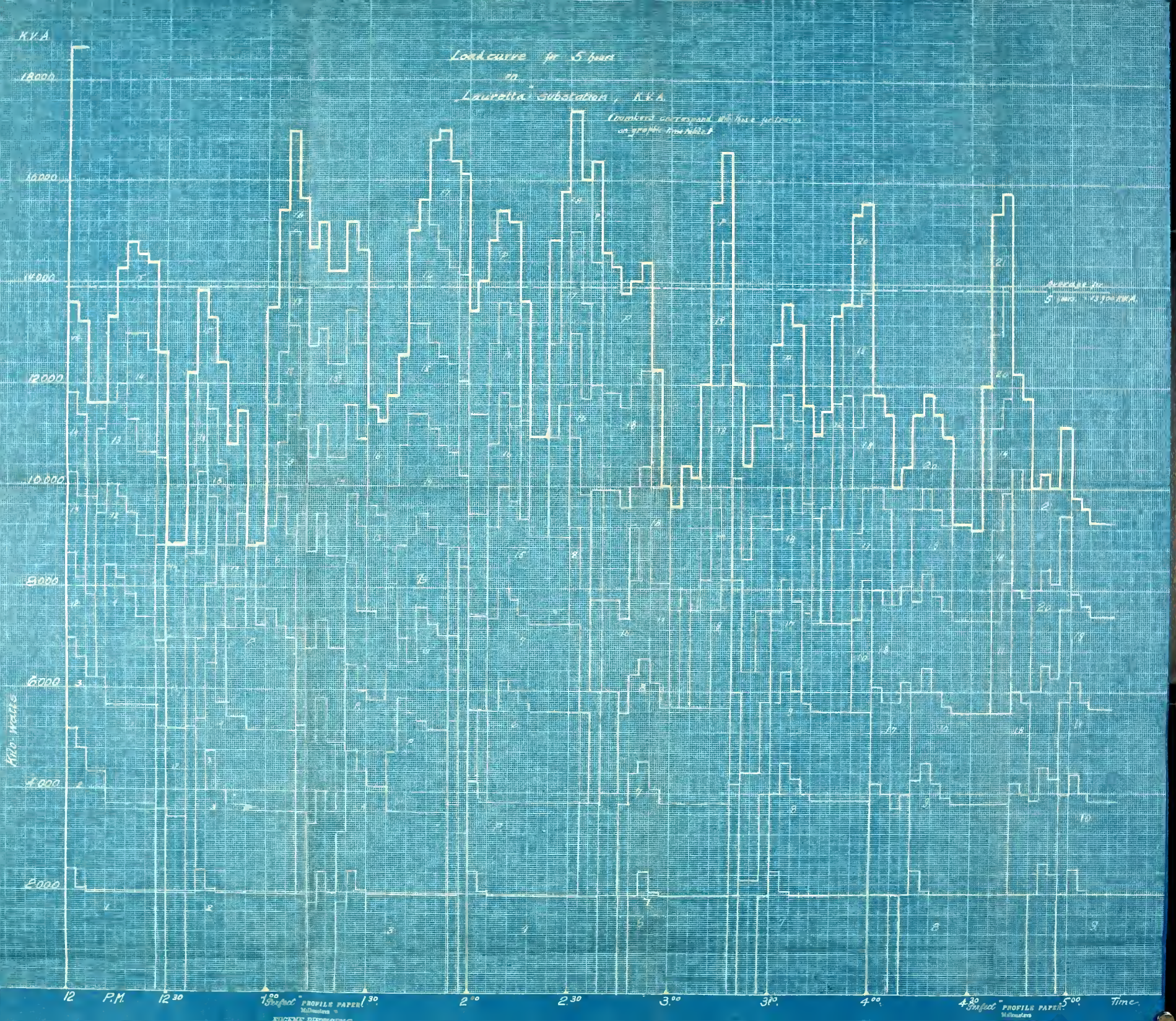


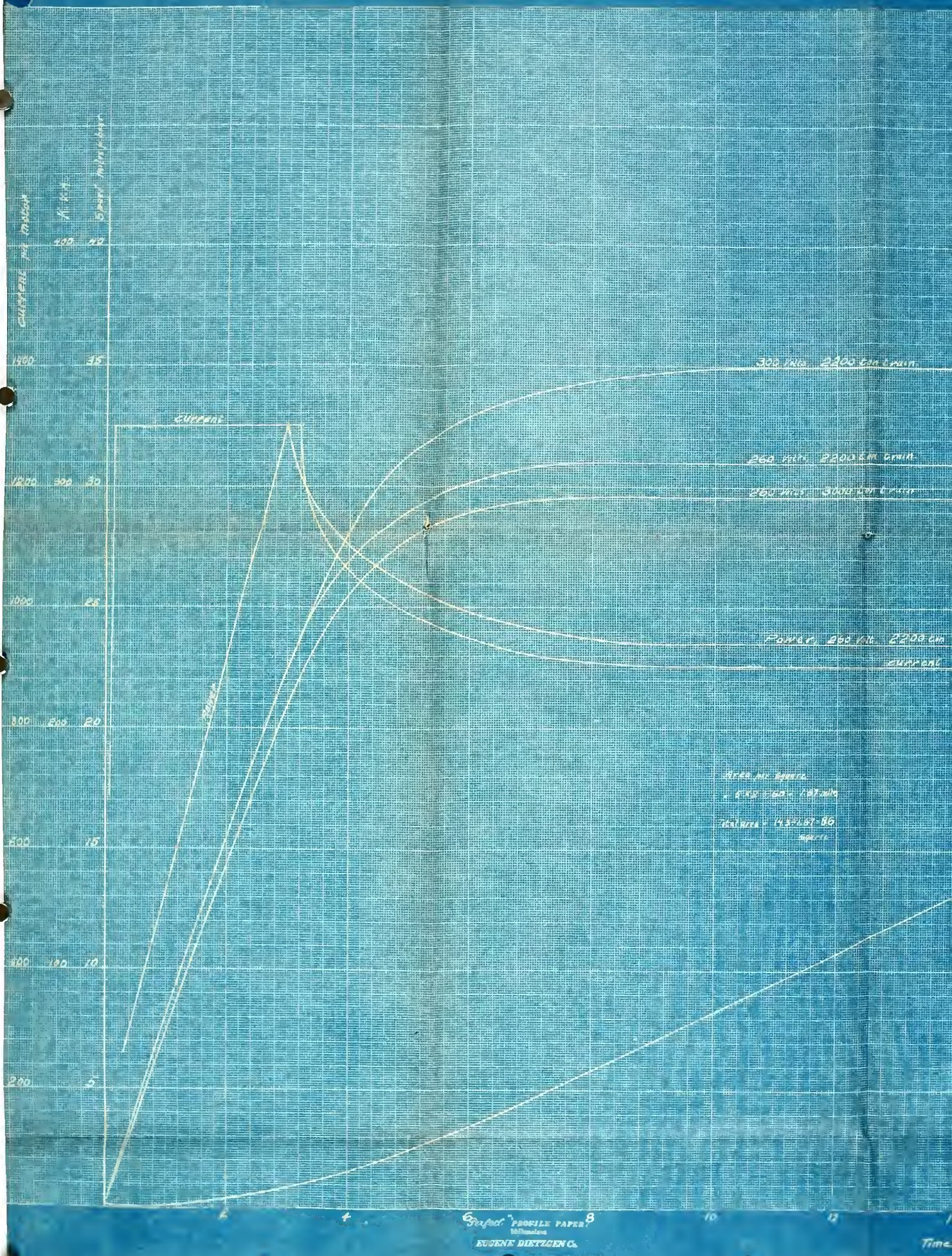

Catenary for proposed trunk line Electrification

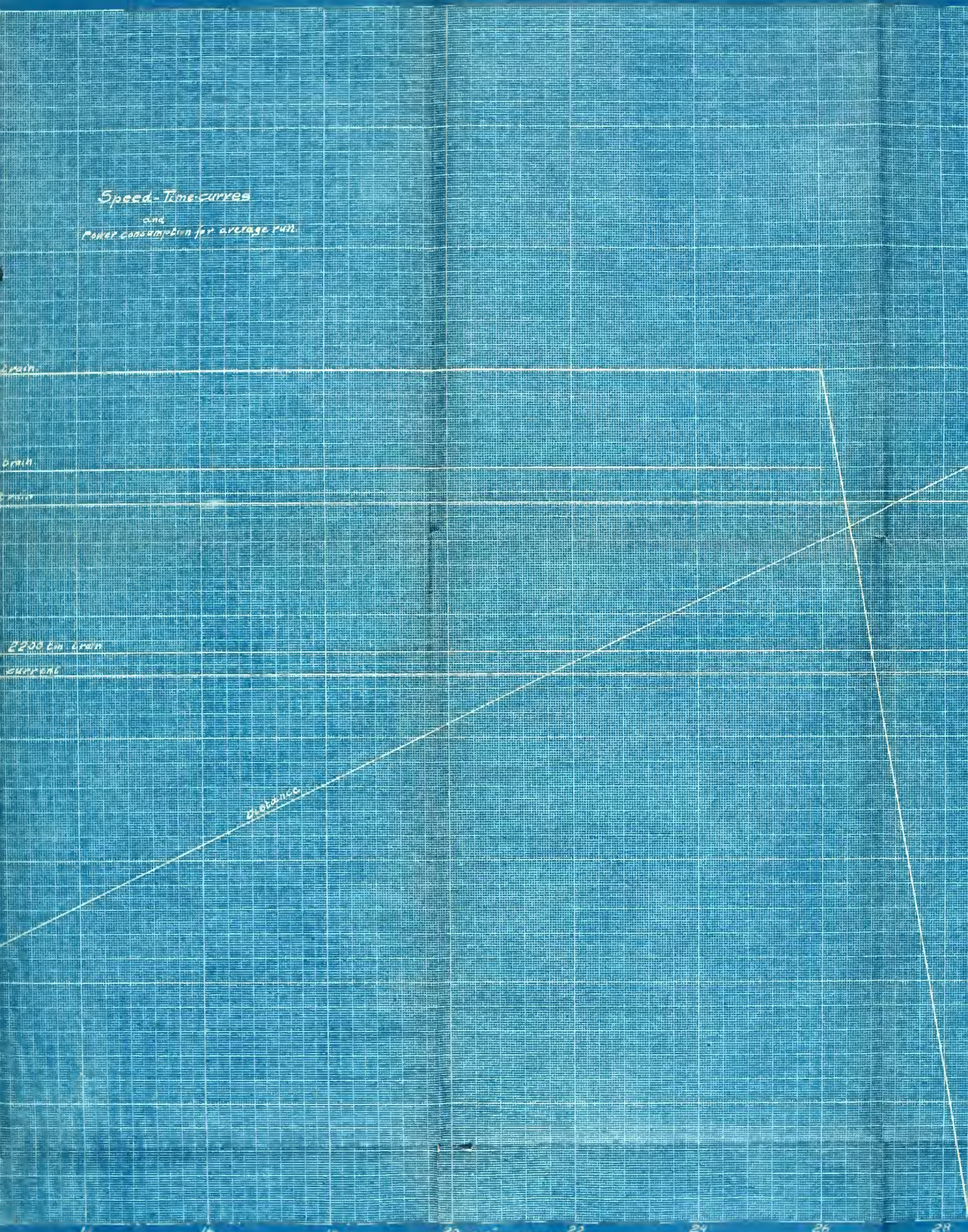
Sag at 50°F - 6'-0"
Tension in messenger cable, 7/16 BS. - 2500 lbs
Tension in 1/0 copper conductors - hung with 3/4" sag

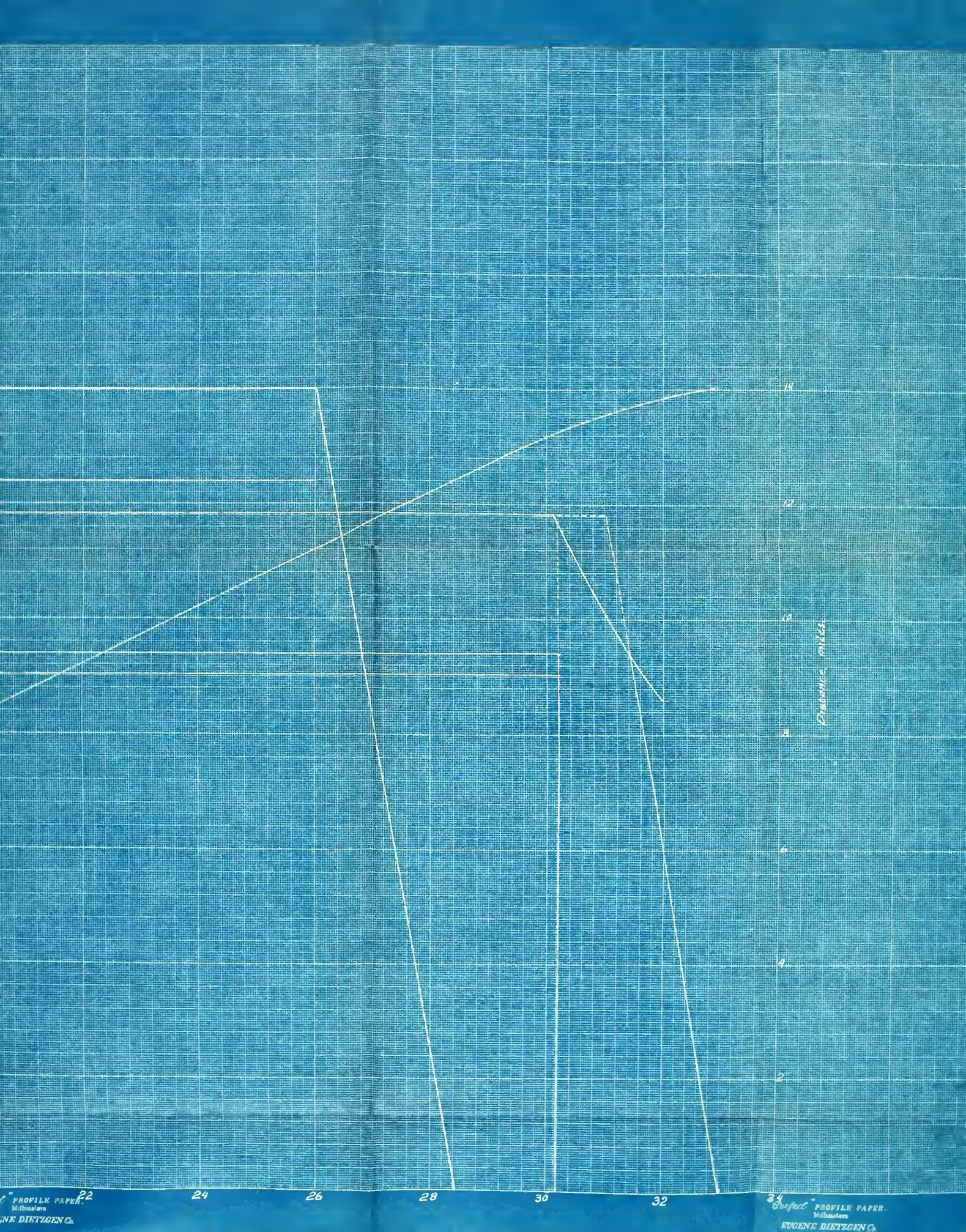

Distribution of Tractive Effort
3000-kw Unit
6 Motors per Locomotive
Tractive effort, lb. per motor
Total resistance
Locomotive resistance
Speed, miles per hour
Gear ratio
Amperes
Gear ratio
Gear ratio
Gear ratio


Total fuel used per hour
6000
5000
4000
3000
2000
1000
Thrust effective LB per hour
Thrust horsepower
Discussion of Engine efficiency
2000 ton trials
8 knots per 1 propeller
Speed
Speed
Speed

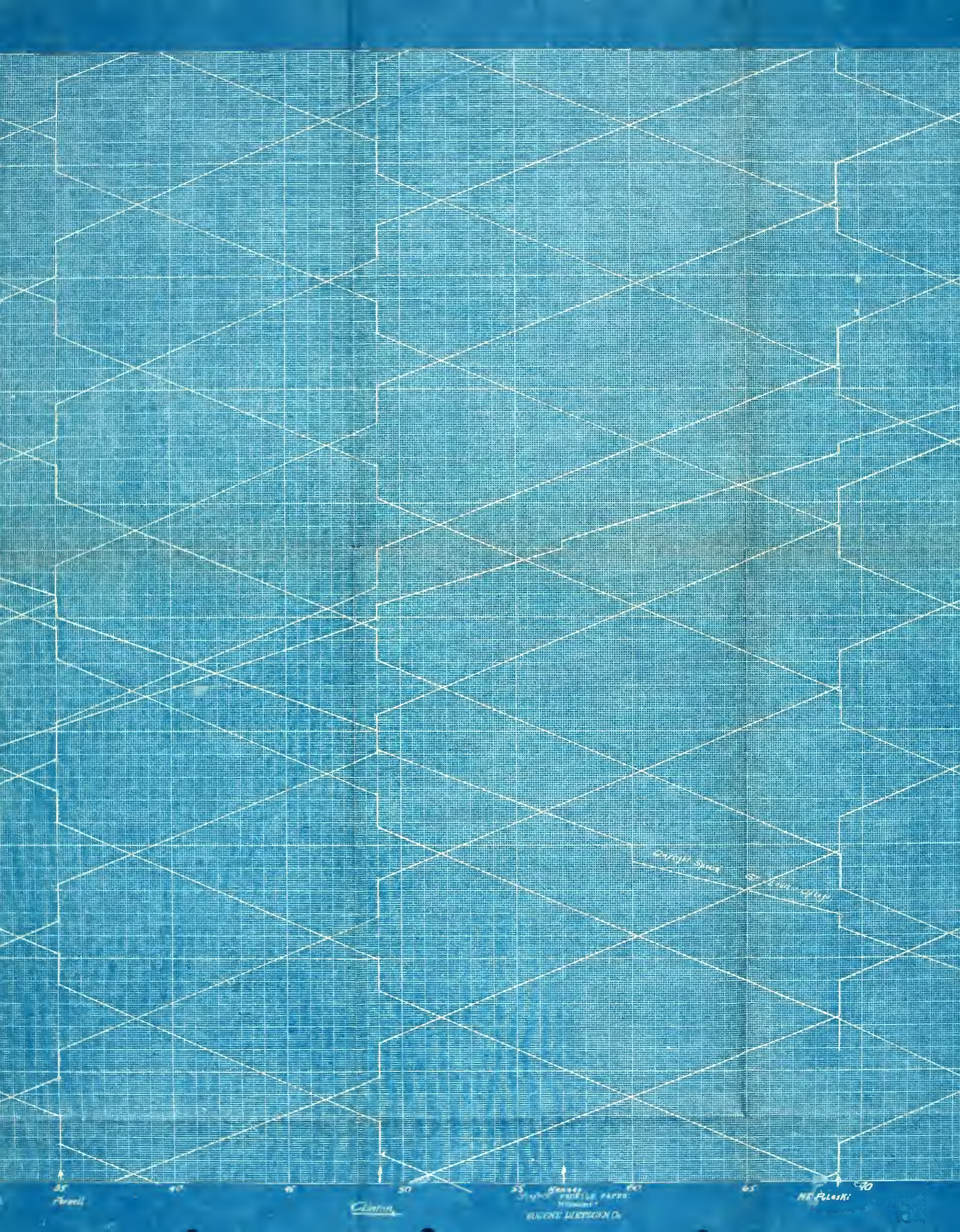

K.V.A
Load curve for 5 hours
on
"Laurelia" Substation, K.E.A.
(numbers correspond to those on graphic time table)
18000
16000
14000
12000
10000
8000
6000
4000
2000
Kilo. Watts
12 P.M.
12 30
1 00
1 30
2 00
2 30
3 00
3 30
4 00
4 30
5 00
Time.
"Imfeld" PROFILE PAPER
Millimeters

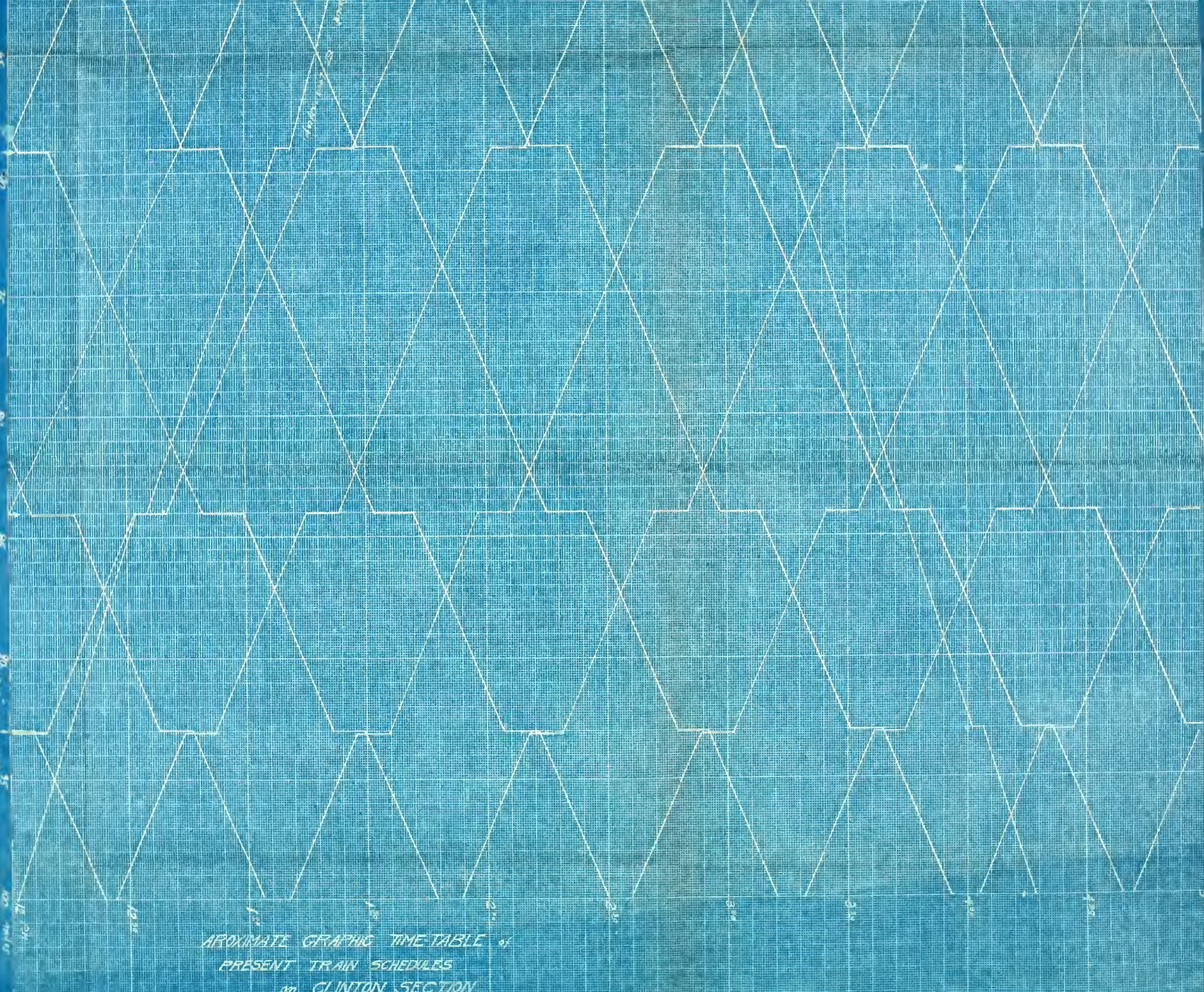

Current
300 Volts 2200 Ohm Grain
260 Volts 2300 Ohm Grain
280 Volts 3000 Ohm Grain
Power 260 Volts 2300 Ohm
Current
Time


Speed-Time-curves
and
Power consumption for average run.
Distance
14
16
18
20
22
24
26
28
Time. minutes.


22
24
26
28
30
32
34
PROFILE PAPER.
Millimeters
EUGENE DIETZGEN Co.

Melvin
10
Gibson City
15 miles
20
25
30
35
Arcola


35
Powell
40
45
50
Clinton
55
Kansas
60
65
70
NE Pulaski



APROXIMATE GRAPHIC TIME TABLE of
PRESENT TRAIN SCHEDULES
on CLINTON SECTION